MMET 376

STRENGTH OF MATERIALS

LAB MANUAL

Dr. Muzammil Arshad

About the Author

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Foreword

The primary purpose of the laboratory part of MMET 376 (Strength of Materials) is to show students the experimental methods of determining the magnitudes of stresses and strains acting in a material. These values can be further used to determine other material properties.

In order for the students to achieve a good understanding of the theoretical concepts for the underlying experiments, the entire course is designed such that classroom lectures precede/augment lab work. Students are advised to pay close attention in class so that they can perform well in the lab.

Although there are various methods of Experimental Stress Analysis (ESA), the lab manual will focus only on Strain Gauge Technique. It is inexpensive and the most widely used. Lab 1 and Lab 2 deal with installation of strain gauges. Students are advised to pay close attention to those labs, as these labs are the foundation of the labs that will follow afterwards.

Lab Policy

Groups

Students will be formed into **groups of three or four on the first lab day**. Once a student has signed up with a group, he or she may not change groups without prior approval of the instructor.

Lab Reports

You will perform the experiment in group, and turn in **ONE REPORT PER GROUP**. Your report should be self-contained, i.e. an engineering technologist should be able to perform the experiment and duplicate your results by reading your report. **DO NOT "adjust"** your data to make them fit what you believe to be an acceptable value. Your report should be an accurate description of the experiment. If your results differ significantly from reference values you should check your settings carefully (calibration, wrong units, wrong calculations, etc.), and do the experiment again. Try to explain any discrepancies but do not "adjust" your data. Lab report format and rubric will be shared as a separate document.

Attendance

Attendance will be taken at the beginning of every lab session. Make up lab activities will be scheduled only for University approved absences or unless the instructor gives prior approval. If you miss the lab, you will be assigned zero grade for that day's experiment and the subsequent lab report. During the lab time, you cannot leave without the instructor's permission.

Students with disabilities

If you feel you are entitled to special accommodations because of a disability, please see me within the first four class meetings. You may also want to review the **Americans with Disabilities Act policy statement**.

Strength of Materials Lab Policy

We want to maintain the high-quality conditions of this lab for the students in future years. Thus, it is necessary for you to adhere to the established policy of **NO BEVERAGES, FOOD, NEWS PAPERS, MAGAZINES, TOBACCO PRODUCTS AND ANIMALS** within the Strength of Materials lab. You cannot take or use the chemicals, tools, and instruments without the TA's permission.

Safety

It is required to wear long pants and shoes that cover toes for this Lab. NO SHORT PANTS, SLIPPERS AND TANK TOPS. Safety glasses will be needed for several labs.

Policy Compliance

By signing this form, I verify that I will read, understand, and agree to follow the safety practices required for this course as established by the professor, by the Look College of Engineering, by the Engineering Safety Office, and by Texas A&M University. I will locate all emergency equipment and personal protective equipment (PPE), I will learn how to use the PPE, and I will always use the appropriate PPE for the work that I am doing.

I fully commit to conducting my studies in a safe, healthful and secure manner, in compliance with the *Aggie Honor Code*, the *Engineering Code of Ethics*, and by the established safety rules, in order to reduce risk to myself and others, and to facilitate the safe and successful completion of this Engineering course.

Within the first two (2) weeks of the semester, I will logon to the *Engineering Safety Net* web site at http://engineering.tamu.edu/safety/ and complete the online *Laboratory Safety Training*. If my laboratory work involves the use of tools, I will also complete the online *Shop & Tool Safety Training*. I will complete any other necessary safety training as directed by my professor.

I acknowledge that while in the laboratory, improper conduct and horseplay of any kind that may endanger others or myself will not be tolerated and appropriate disciplinary action will be taken. I will never work in the laboratory alone, and I will never leave an experiment running unattended. I understand that I may be dismissed from this laboratory course for failure to comply with the established safety procedures for this laboratory and with all TAMU & TEES Safety Rules.

First Name: **Family Name:**

UIN:

SIGN: **DATE:**

Lab 1 & 2: Installation of Strain Gauges

Objective:
To familiarize students with various construction features of bonded type resistance strain gauge and to install strain gauges on real life specimens.

Theory:
Out of the various experimental stress analysis techniques, strain gauging is the most practical and frequently used because it is inexpensive, easy to handle, easy to install and long lasting. A strain gauge is an electrical resistance gauge which has a very thin metal foil grid made from a strain sensitive material, such as constantan, with an insulating backing. The gauge is carefully bonded to the surface of the component - with a special adhesive - where critical stresses are likely to occur. When the component is loaded, the gauge experiences the same strains as the surface due to which the total length of the gauge wire changes and hence changes the resistance of the gauge. The gauge is connected into an electrical measurement circuit called a Wheatstone Bridge circuit whose measured voltage across the diagonal changes with the change in resistance. This voltage reading can be converted to the experienced value of strain when a calibration factor called the **gauge factor** is applied.

Experiment:
Two strain gauges are to be installed on an aluminum beam and two strain gauges are to be installed on a soda can during a two-lab exercise. On the aluminum beam, the gauges should be installed on its two faces, and on the soda can, the strain gauges will be diametrically opposite to each other. In the first lab, install **one** strain gauge each on the aluminum beam and the soda can along the longitudinal direction (as shown in Fig 1a and 2a) and in the second lab, mount the other strain gauge on the beam and the soda can along transverse direction (as shown in Figures 1b and 2b).

The beam with installed gauges will be used in the determination of Modulus of Elasticity and Poisson's ratio of Aluminum and the Soda Can will be used in the determination of Hoop and Longitudinal stresses.

Procedure:
Students will be shown a video about strain gauge installation procedure. The instructions from the video should be followed closely (Some of the instructions in the video are modified as per the lab convenience). They are repeated in the **Student Manual for Strain Gauge Technology** from *Measurements Group*. Follow this Manual closely for Strain Gauge installations in lab 1 & 2.

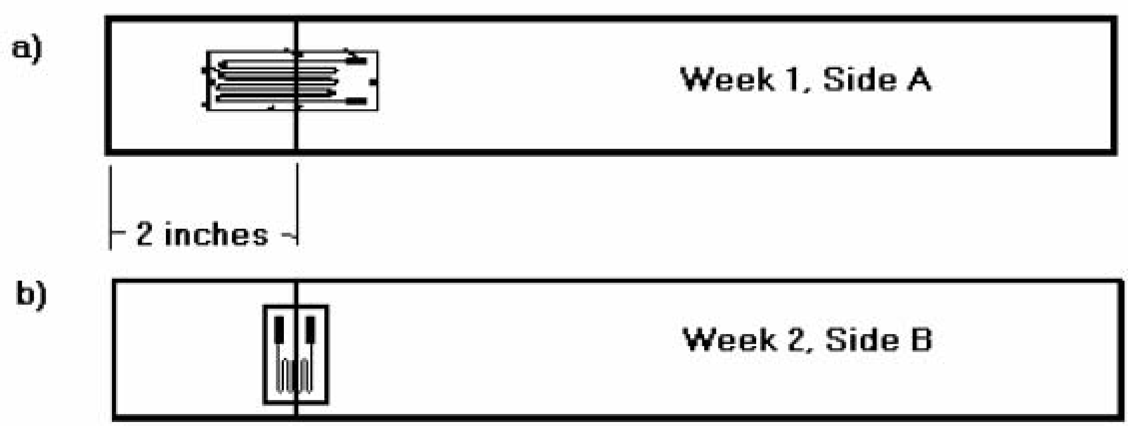


Fig 1 - Strain gauge installation on both faces of an aluminum beam sample

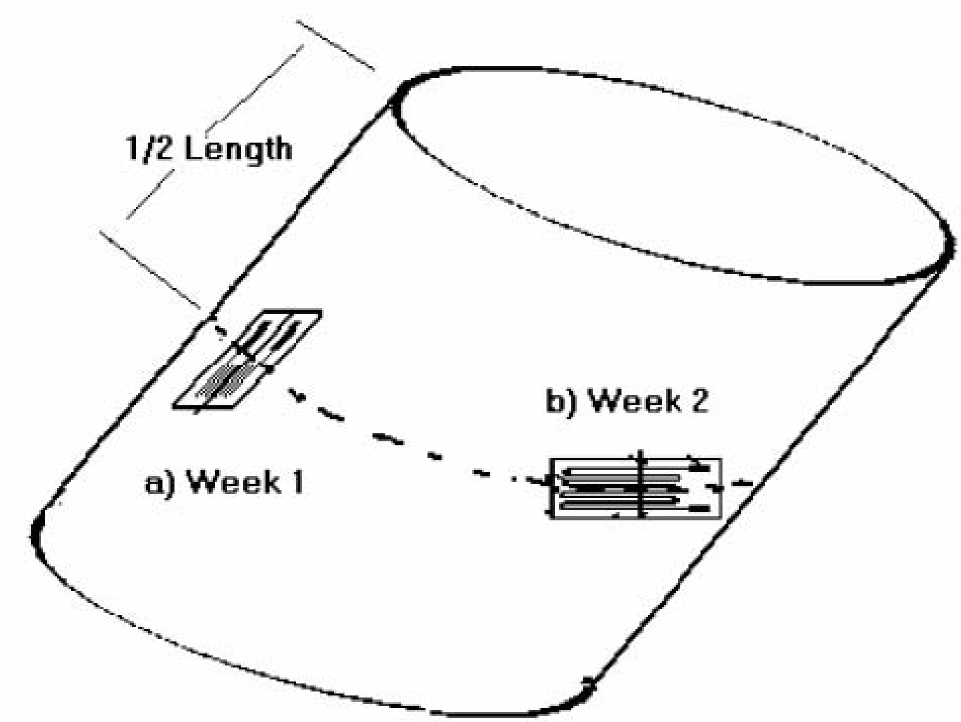


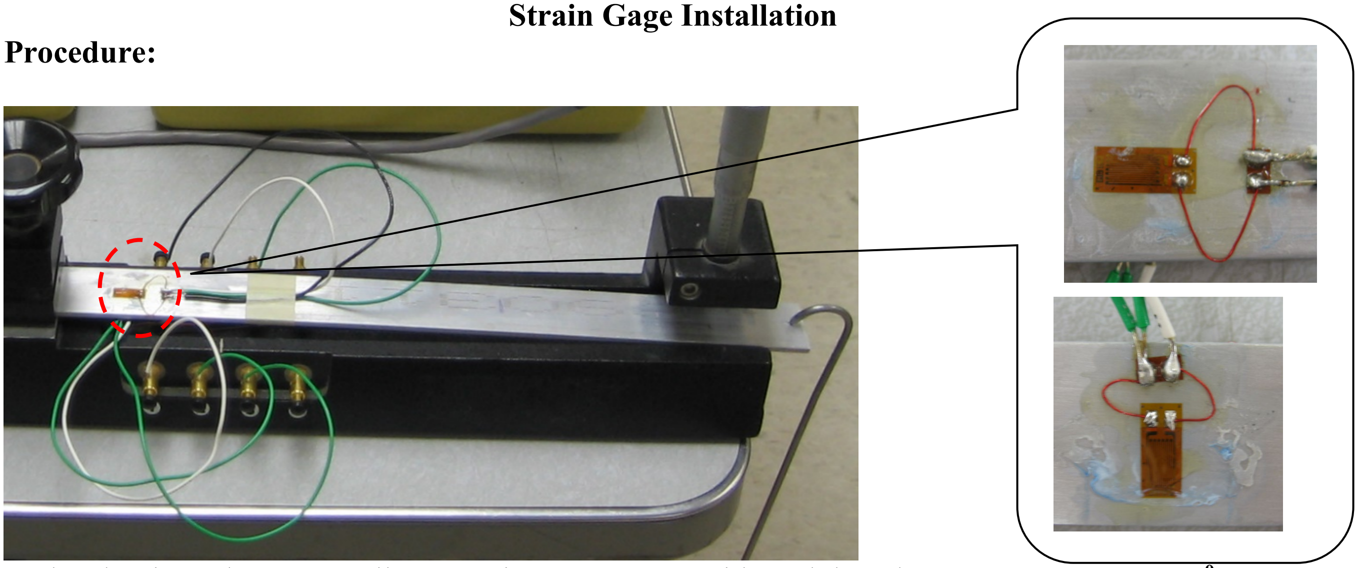
Fig 2 – Strain gauge installation on a soda can (the strain gauges are diametrically opposite)

Note:

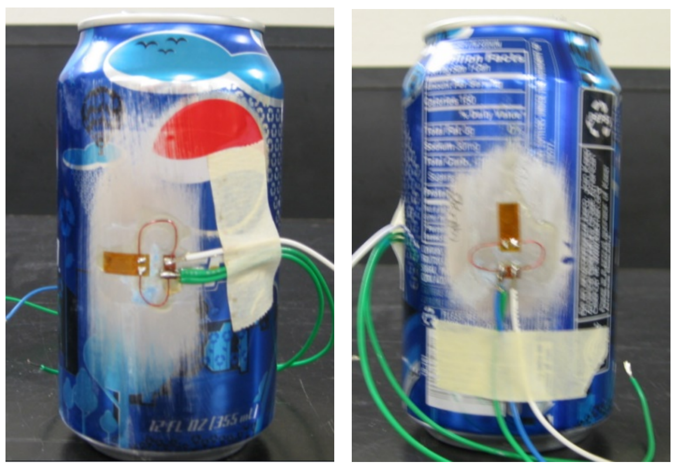
1. On the aluminum beam (Fig 1), the end with a dent near it will be the free end, and the other end will be the fixed end. So, while installing the strain gauges, please make sure that you don't install them near the free end. Also make sure that the strain gauges are installed at a distance of 2 inches from the fixed end.
2. The longitudinally installed strain gauge i.e., along the length of the beam should preferably be on the dented face of the aluminum beam.
3. Make sure that the terminals are towards the free end of the aluminum beam.
4. On the soda can (Fig 2), strain gauges should be installed at ½ the length of the can; one along the circumference and one along the length.

Strain Gage Installation

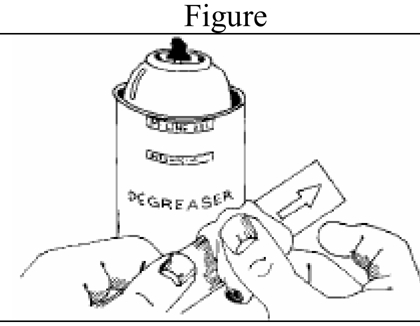
Procedure:

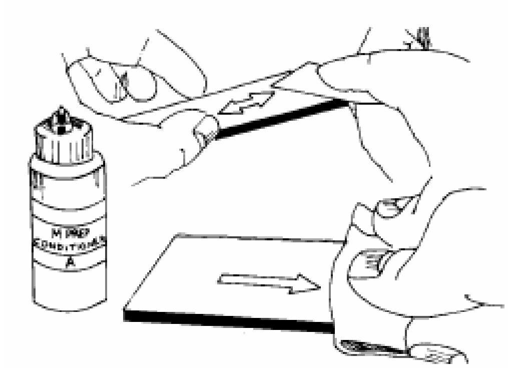
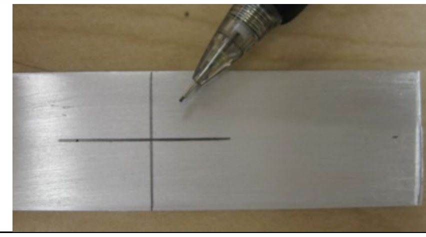
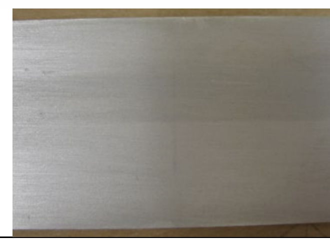
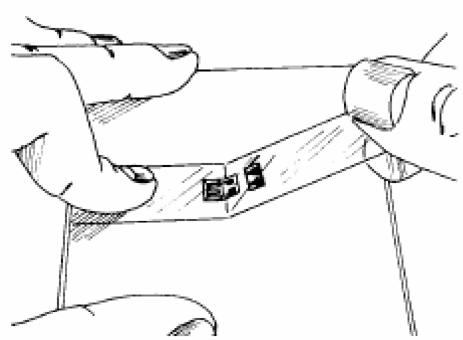


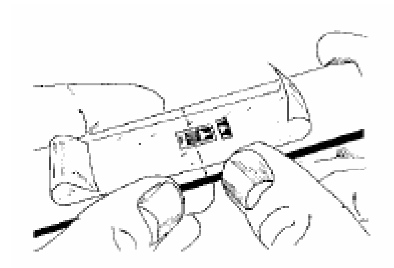
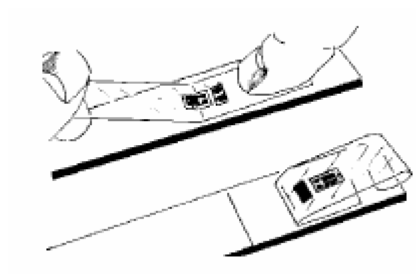
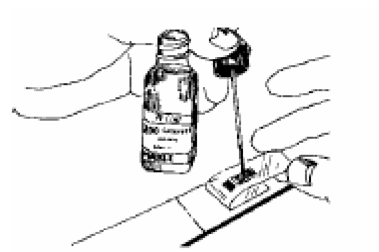
The aluminum beam: Install two strain gages on one side and the other, **note they are in 90^0 angles**.

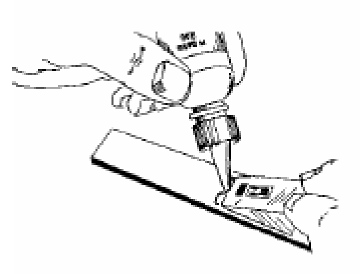
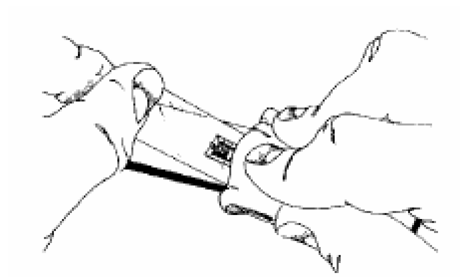
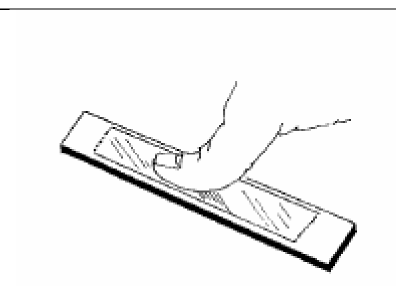
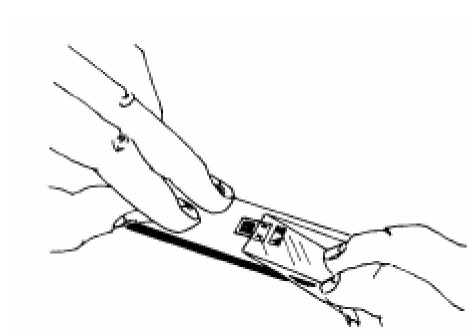


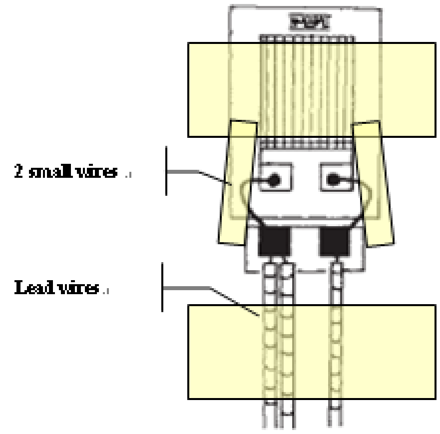
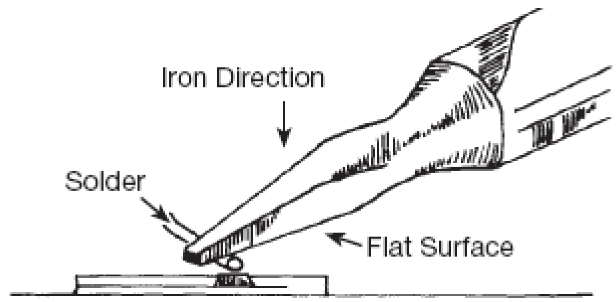
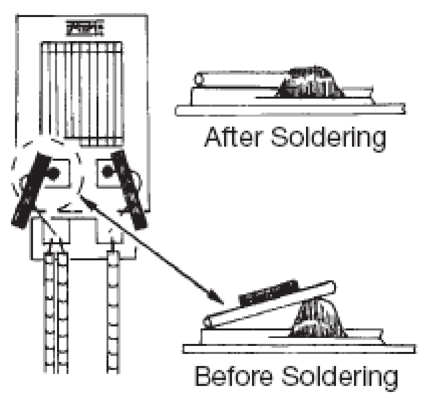
The soda can also install two strain gages and with **90^0 angles**.

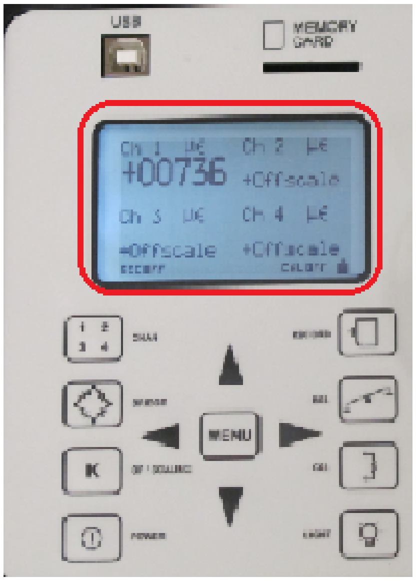
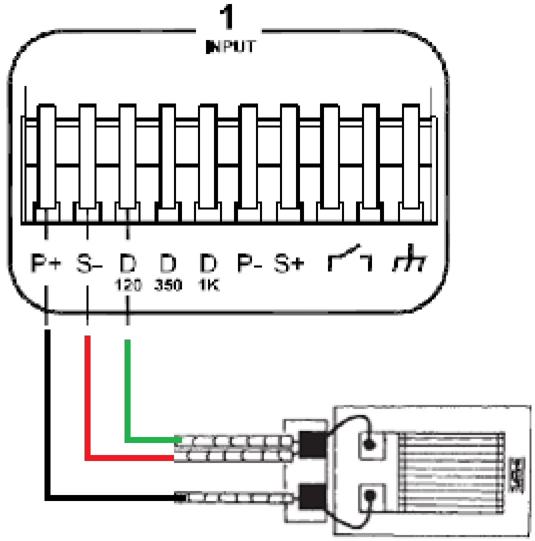
STEP	Description	Figure
1	Thoroughly degrease the gaging area with solvent, such as CSM Degreaser	

2	Abrading is done by using 400-grit silicon-carbide paper on surfaces thoroughly wetted with **M-Prep Conditioner A (Soapy water)**, then dry by slowly wiping through with a gauze sponge. Using a 4H pencil (on aluminum) or a ballpoint pen (on steel), burnish (do not scribe) whatever alignment marks are needed on the specimen.	 
3	Now apply a liberal amount of M-Prep Neutralizer 5A (Soapy water) and scrub with a cotton-tipped applicator. Scrub slowly until the cross can barely be recognized. With a single, slow wiping motion of a gauze sponge, carefully dry this surface. Do not wipe back and forth because this may allow contaminants to be redeposited.	 
4	Using tweezers to remove the gage from the transparent envelope, place the gage (bonding side down) on a chemically clean glass plate or gage box surface. If a solder terminal will be used, position it on the plate adjacent to the gage as shown. A space of approximately 1/16 in [1.6 mm] or more where space allows or application requires should be left between the gage backing and terminal. Place a gage installation tape (transparent one) over the gage and terminal. Take care to center the gage on the tape. Carefully lift the tape at a shallow angle (about 45 degrees to specimen surface), bringing the gage up with the tape as illustrated above.	

5	Position the gage/tape assembly so that the triangle alignment marks on the gage are over the layout lines on the specimen. If the assembly appears to be misaligned, lift one end of the tape at a shallow angle until the assembly is free of the specimen. Realign properly, and firmly anchor at least one end of the tape to the specimen. Realignment can be done without fear of contamination by the tape mastic if transparent tape is used, because this tape will retain its mastic when removed.	
6	Lift the gage end of the tape assembly at a shallow angle to the specimen surface (about 45 degrees) until the gage and terminal are free of the specimen surface. Continue lifting the tape until it is free from the specimen approximately 1/2 in [10 mm] beyond the terminal. Tuck the loose end of the tape under and press to the specimen surface so that the gage and terminal lie flat, with the bonding surface exposed. Note: If contaminated, the back of any gage can be cleaned with a cotton-tipped applicator slightly moistened with **M-Prep Neutralizer 5A**. (water)	
7	M-COAT catalyst (no catalyst) can now be applied to the bonding surface of the gage and terminal. The adhesive will harden without the catalyst, but less quickly and reliably. Very little catalyst is needed, and it should be applied in a thin, uniform coat. Lift the brush-cap out of the catalyst bottle (no catalyst) and wipe the brush approximately 10 strokes against the inside of the neck of the bottle to wring out most of the catalyst. Set the brush down on the gage and swab the gage backing. Do not stroke the brush in a painting style, but slide the brush over the entire gage surface and then the terminal. Move the brush to the adjacent tape area prior to lifting from the surface. Allow the catalyst to **dry at least one minute**.	

<table>
<tr><td>8</td><td>Lift the tucked-under tape end of the assembly, and, holding in the same position, apply one or two drops of M-Bond 200 (substitute glue) adhesive at the fold formed by the junction of the tape and specimen surface. This adhesive application should be approximately 1/2 in [13 mm] outside the actual gage installation area. This will insure that local polymerization that takes place when the adhesive comes in contact with the specimen surface will not cause unevenness in the gage glueline.</td><td>STEP 8, 9 & 10 should complete within 3-5 sec
</td></tr>
<tr><td>9</td><td>Immediately rotate the tape to approximately a 30-degree angle so that the gage is bridged over the installation area.
While holding the tape slightly taut, slowly and firmly make a single wiping stroke over the gage/tape assembly with a piece of gauze bringing the gage back down over the alignment marks on the specimen.
Use a firm pressure with your fingers when wiping over the gage. A very thin, uniform layer of adhesive is desired for optimum bond performance.</td><td></td></tr>
<tr><td>10</td><td>Immediately upon completion of wipe-out of the adhesive, firm thumb pressure must be applied to the gage and terminal area. This pressure should be held for at least one minute.</td><td></td></tr>
<tr><td>11</td><td>The gage and terminal strip are now solidly bonded in place. It is not necessary to remove the tape immediately after gage installation. The tape will offer mechanical protection for the grid surface and may be left in place until it is removed for gage wiring.
To remove the tape, pull it back directly over itself, peeling it slowly and steadily off the surface. This technique will prevent possible lifting of the foil on open-faced</td><td></td></tr>
</table>

	gages or other damage to the installation.	
	Before **Soldering** Mask the strain gage by **'drafting tape'**, and tape the lead wire & two "small-wire" that connect the strain gage and copper-pad	
12	**Soldering tip** 1. Tin the terminal and wire	
		
13	**Test**	

	  When it appears some value, that means soldering is good !! **If there is no value at the LED screen, check the connection & soldering again**	
14	**Remove the drafting tape** Apply some rosin solvent (soapy water) on the drafting tape, and then use the brush **SLIGHTLY** removes the tape.	 **M-LINE Rosin Solvent**
15	**Apply M-Coat A** Apply the M-Coat A (no M-Coat A) on the gage area & copper pad area Label the specimen with your group name by the draft-tape	

Lab 3: Tensile Test with United Model SFM Test System

Objective:
To develop an understanding of stress-strain curves of materials, and learn how to use them to determine various mechanical properties of ductile and brittle materials.

Theory:
The tensile test provides information on the strength of a material under uniaxial tensile stress. It can be used to obtain the stress-strain curve of a material that will show the relationship between the stress and strain of that material as shown in Figure 3b.

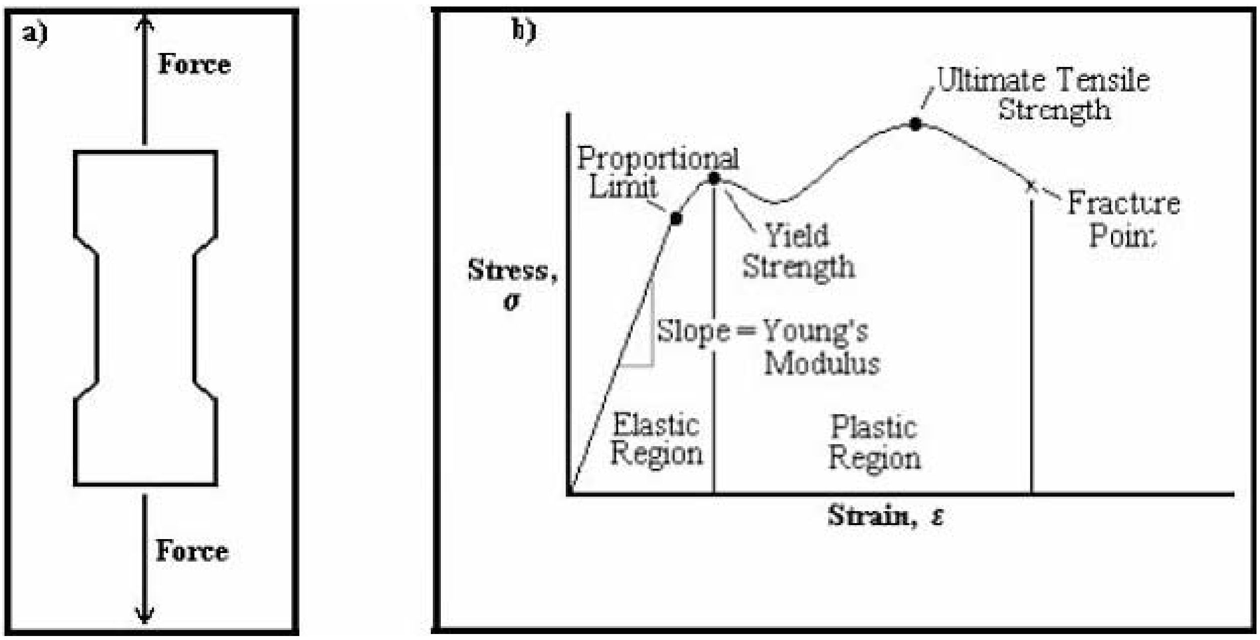


Fig 3 a) Tensile test specimen **b) A typical stress- strain curve for a ductile material**

From the stress-strain curve, various mechanical properties of the material, such as Young's Modulus (Modulus of Elasticity), Yield Strength, and the Ultimate Tensile Strength, can be determined.

1. Young's Modulus (Modulus of Elasticity)
In the region on the stress-strain curve where the stress changes linearly with the strain, the Young's modulus (Modulus of elasticity, E) is defined as the ratio of stress and strain. Value of the Young's modulus is a constant for a given material.

2. Yield point
Yield point is a point on the stress-strain curve, after which there is a significant increase in strain with little or no increase in stress. The corresponding stress is called the Yield Strength of that material. For materials that do not possess well- defined yield point, "offset method" is used to determine it.

3. Proportional limit
Proportional limit is the value of stress on the stress-strain curve at which the curve first deviates from a straight line.

4. Elastic Limit
Elastic limit is the value of stress on the stress-strain curve after which the material deforms plastically; that is, it will no longer return to its original size and shape after unloading it.

5. Ultimate tensile strength
Ultimate tensile strength is the highest value of apparent stress on the stress-strain curve.

6. Elastic Deformation
A material under loading is said to have undergone elastic deformation if it reverts back to its original shape and size upon unloading it.

7. Plastic Deformation
A material under loading is said to have undergone plastic deformation if it is permanently deformed upon unloading it.

Fig 4 - Universal Testing Machine and Control Unit

Fig 5 – Strain Gage

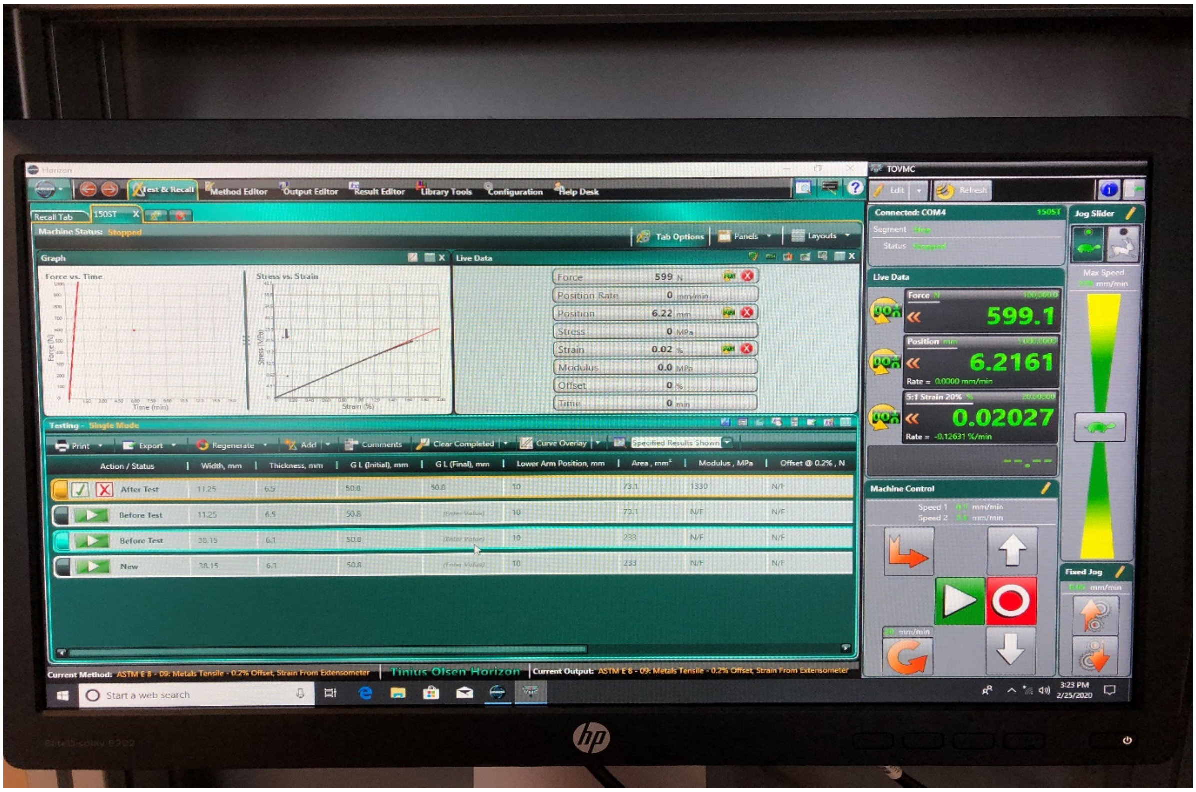


Fig 6 – Computer Software Interface

Experiment:

A tensile testing machine applies a controlled load on a specimen slowly and steadily, stretching the specimen until it fractures. Fig 4, 5 and 6 shows a tensile testing machine connected to a control unit and computer software interface and the strain gage. The user specifies test parameters such as type of test, units, preload, crosshead speed, and extensometer. The computer controls most of the testing process, including recording the applied load, strain and generating the stress-strain curve.

Students are required to perform tensile tests for two different materials (brittle and ductile), and then use the stress-strain data to calculate the material properties for each material. The calculated values should then be compared with published material properties. The two different materials used are brass and steel. Brass is a brittle material whereas steel is a ductile material.

Equipment:

United SFM Test System
Extensometer - to measure the elongation in the mid-section of the specimen.
Two test specimens (steel and brass)
Ruler and calipers - to take measurements.

Procedure:

There are six steps involved in each tensile test:

1. Specimen preparation
2. Setting test parameters
3. Running the tensile test
4. Remove extensometer at 1.5% strain

5. Collecting stress-strain data
6. Calculating material properties
7. Evaluating experimental results

Test Parameters:
Initial Gage length = 2” = 50.8 mm

Specimen Dimensions:

Steel:	b = ______ in	t = ______ in
Brass:	b = ______ in	t = ______ in

where b=width and t=thickness at the center of the specimen.

Published Values:
$E_{steel} = 29 \times 10^6$ psi = 200 GPa
$E_{brass} = 16 \times 10^6$ psi = 110 GPa

Step by Step Procedure:
1. Switch on the computer.
2. Double-click the “Horizon” icon on the Desktop. It will open up the computer software interface.
3. Wait for the software to load. This window will have different options like ‘Exit’, ‘New’, ‘Open’ etc. Click on “New” and a table will open.
   a. Click on “1. Templates” tab and select “ASTM E8-09: Metals Tensile – 0.2% Offset, Strain from Extensometer".
   b. In the gage length, enter the value of the gage length. In the measurement, give a spec id (Brass or Steel) to your specimen, and enter the width and the thickness of the specimen. After entering the thickness, press “Enter” and the system will calculate the cross section area of specimen automatically.
4. Mark the gage length of 2 inches on the specimen and fix the specimen in the jaws. To bring the upper block with chuck down, “tortoise” or “hare” icons could be chosen for the speed. For proper gripping, the entire length of the serrated face of each wedge must be in contact with the specimen. Use the control unit, turn the knob to tighten the wedges around the specimen. The pressure of 2000 psi would show on the control unit after the jaw grips the specimen.
5. Go back to the test window.
   a. Before test, zero the force, position and strain.
   b. Clamp the extensometer on the specimen and remove its pin so the extensometer is free to move during test and record strain.
   c. The speed of the machine can be chosen in the “Method Editor” and clicking the tab “Control Segments”. Choose the “Control Value” to be 1 mm/min.
   d. Under “Action/Status”, click on the play icon tab. Press "enter" button and the test will continue.
   e. After the Strain reaches 1.5%, take off the extensometer. The test will keep going until the specimen breaks.
   f. After the specimen breaks, input the value of the deformed gage length in the message box. Loosen the jaws from the control unit and retrieve the specimen. Measure the new gage length and enter the value in the message box. Also, measure the new thickness and width.
6. Click on “Print” tab and save the plot as a PDF file.

Stress-Extension graph is plotted by the software from the data collected from the extensometer. It contains only the data until 1.5% strain which is measured by the extensometer. Whereas, Stress Position plot is the plotted by the software from the positional data of the jaws from the machine. It contains the entire data of stress-position until the specimen breaks.

Final Gage Length (Brass): ______ in
Final Gage Length (Steel): ______ in

Required:

1. On the stress-extension and stress-position graphs show the following points:
   a) Ultimate strength
   b) Yield Point (only for steel)
   c) Fracture Point
   d) Elastic Deformation Region
   e) Plastic Deformation Region
   f) Proportional Limit
2. Calculate the Young's moduli from the stress-strain graph.
3. Calculate the elongation percentage.
4. Compare the experimental results with published values and quantify the errors.

Lab 4: Tensile Test for Anisotropic Materials

Objective:
To develop an understanding of anisotropic materials, and learn how the material orientation make the material properties different.

Theory:
Fused deposition modeling (FDM^{TM}) is a rapid prototyping process that is patented as a technology and commercially marketed by Stratasys, Inc. In this process also, as with most rapid prototyping process, the part is deposited layer by layer; the layer itself, being deposited strand by strand. The products or the specimens made by the FDM are considered as the anisotropic material, which means the material properties will be different at different directions. The figures below show that the different deposition strategies may cause the different material properties.

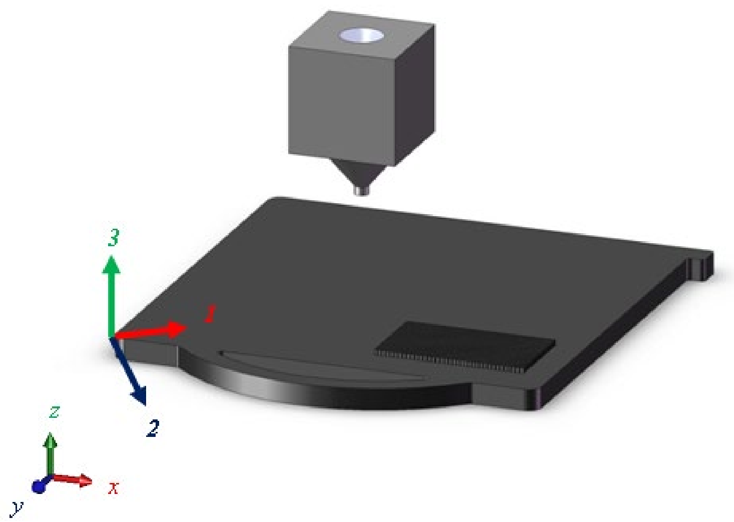


Fig. 1. Schematic of the FDM nozzle and platen

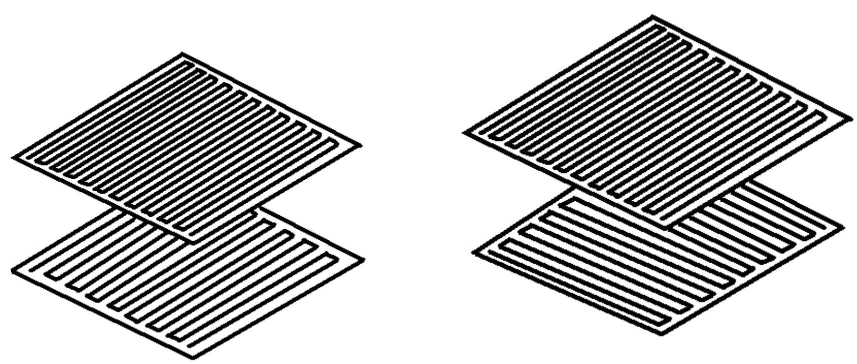


Fig. 2. A schematic of the unidirectional (left) and crisscross (right) deposition strategies

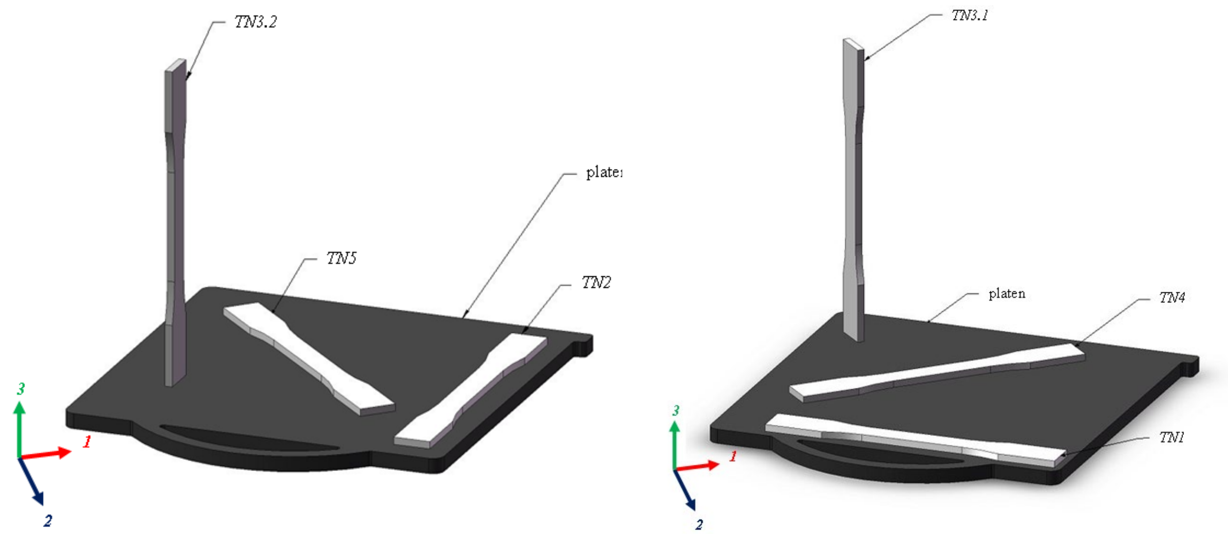


Fig. 3. A schematic of the 5 different tensile test specimen configurations that were printed in different build and raster orientations

The specimens for this lab are made of acrylonitrile butadiene styrene (ABS) on a Stratasys Uprint SE Plus 3D-printer. Only crisscross deposition strategy (Figure 2) is possible with this printer, where the filament strands are in perpendicular directions in alternate layers. Three tensile specimens TN2, TN3.1 and TN5 specimens are tested in this lab. Young's modulus of the specimens depends on the build and raster orientations of the specimens. Hence, anisotropy can be achieved by changing the build and raster orientations of the specimen.

Build orientation refers to the orientation of the geometry of the specimen with respect to the build plate (i.e., flat, on edge, upright). In the above figure TN1, TN2, TN4, TN5 are printed flat on the build plate while TN3.1 and TN 3.2 are printed upright. **Raster orientation** refers to the direction of the filament strands with respect to the direction of the length of the specimen (i.e., the angle between the strands and the central axis of the specimen). Figure 4 shows the raster angles used for this experiment. For this experiment, we tested two raster orientations ([0º,90º] and [-45º, +45º]) and two build orientations (flat and upright).

Specimen Name	Raster Angle	Build Orientation	Median Young's Modulus(MPa)
TN2	[0º,90º]	Flat	580.64
TN5	[-45º,+45º]	Flat	547.14
TN3.1	[-45º,+45º]	Upright	691.26

Table 1: Specimen Raster Angle, Build Orientation
and Average Young's Modulus

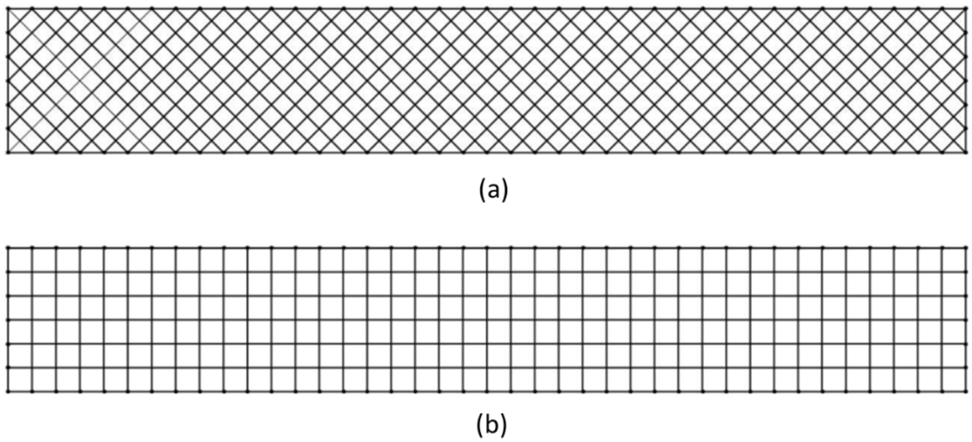


Figure 4: Raster angles (a)cross[0,90] (b)crisscross[-45,+45]

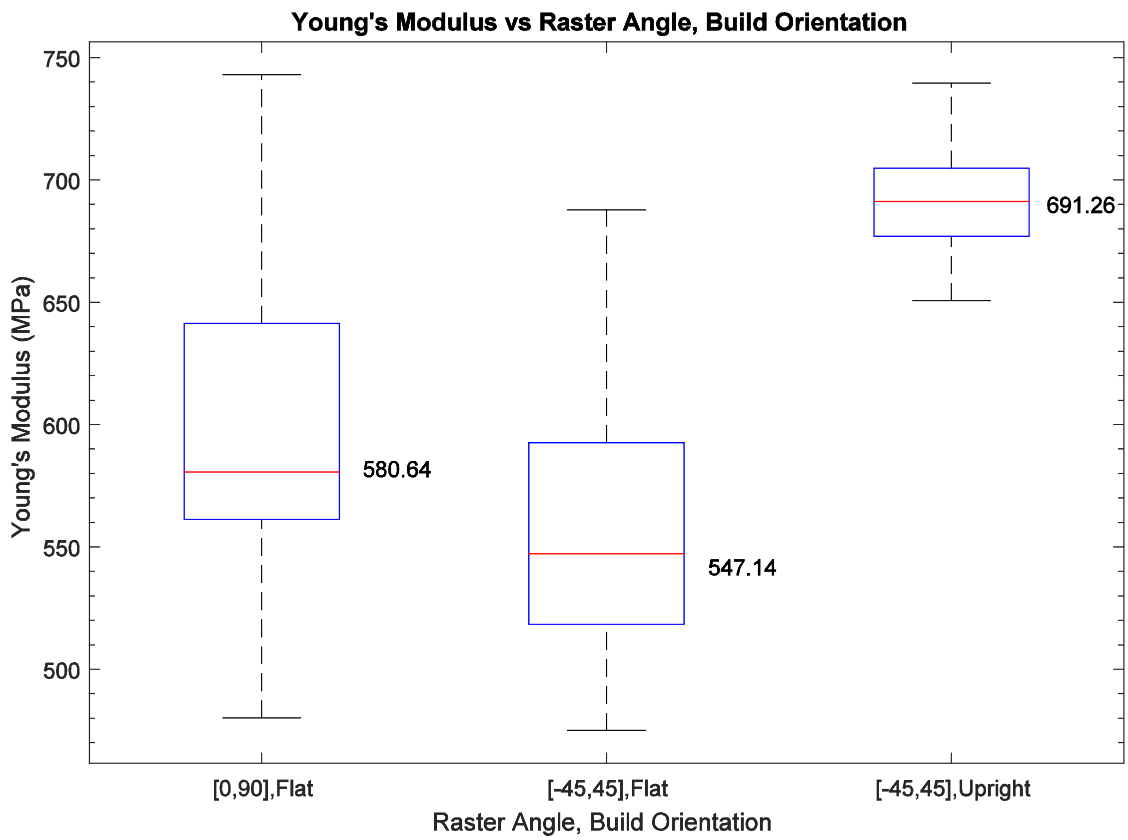
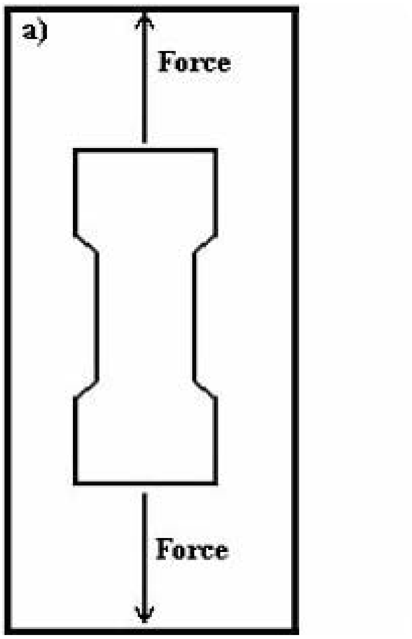


Figure 5: Boxplots showing the statistical data from 19,17 and 5 samples respectively of each orientation in that order.

Method

The tensile test provides information on the strength of a material under uniaxial tensile stress. It can be used to obtain the stress-strain curve of a material that will show the relationship between the stress and strain of that material as shown in Figure 6b.



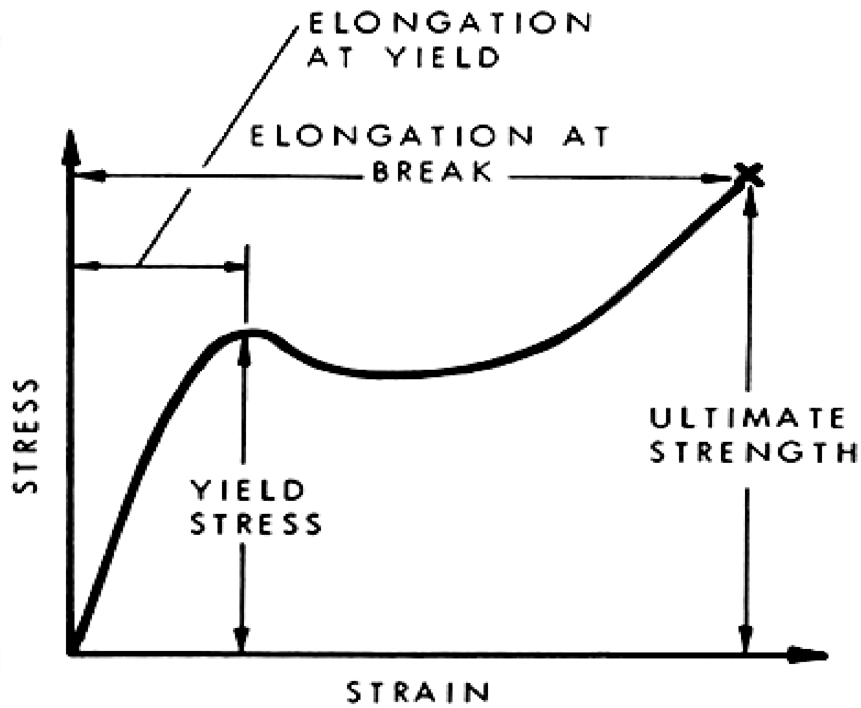


Fig 6 a) Tensile test specimen **b) A typical stress- strain curve for a plastic material**

From the stress-strain curve, various mechanical properties of the material, such as Young's Modulus (Modulus of Elasticity), Yield Strength, and the Ultimate Tensile Strength, can be determined.

1. Young's Modulus (Modulus of Elasticity)
In the region on the stress-strain curve where the stress changes linearly with the strain, the Young's modulus (Modulus of elasticity, E) is defined as the ratio of stress and strain. Value of the Young's modulus is a constant for a given material.

2. Yield point
Yield point is a point on the stress-strain curve, after which there is a significant increase in strain with little or no increase in stress. The corresponding stress is called the Yield Strength of that material. For materials that do not possess well- defined yield point, "offset method" is used to determine it.

Experiment:

A tensile testing machine applies a controlled load on a specimen slowly and steadily, stretching the specimen until it fractures. The user specifies test parameters such as type of test, units, preload, crosshead speed, and extensometer. The computer controls most of the testing process, including recording the applied load, strain and generating the stress-strain curve.

Students are required to perform tensile tests for these anisotropic tensile specimens, and then use the stress-strain data to calculate the material properties for each specimen. The calculated values should then be compared with each other.

Procedure:

There are six steps involved in each tensile test:

1. Specimen preparation
2. Setting test parameters
3. Running the tensile test
4. Remove extensometer at 1.5% strain
5. Collecting stress-strain data
6. Calculating material properties
7. Evaluating experimental results

Step by Step Procedure:

1. Switch on the computer.
2. Double-click the "Horizon" icon on the Desktop. It will open up the computer software interface.
3. Wait for the software to load. This window will have different options like 'Exit', 'New', 'Open' etc. Click on "New" and a table will open.
   a. Click on "1. Templates" tab and select "103 ASTM D 638 Tensile Properties of Plastics".
   b. Click on "2. Scales" and check the type of the "Load cell." Change the load cell to "QSI5156"(The series of 30,000lb load cell.)
   c. In the gage length, enter the value of the gage length. In the measurement, give a spec id (Brass or Steel) to your specimen, and enter the width and the thickness of the specimen. After entering the thickness, press "Enter" and the system will calculate the cross section area of specimen automatically.
4. Mark the gage length of 2 inches on the specimen and fix the specimen in the jaws. To bring the upper block with chuck down, "tortoise" or "hare" icons could be chosen for the speed. For proper gripping, the entire length of the serrated face of each wedge must be in contact with the specimen. Use the control unit, turn the knob to tighten the wedges around the specimen. The pressure of 2000 psi would show on the control unit after the jaw grips the specimen.
5. Go back to the test window.
   a. Before test, zero the force, position and strain.
   b. Clamp the extensometer on the specimen and remove its pin so the extensometer is free to move during test and record strain.
   c. The speed of the machine can be chosen in the "Method Editor" and clicking the tab "Control Segments". Choose the "Control Value" to be 1 mm/min.
   d. Under "Action/Status", click on the play icon tab. Press "enter" button and the test will continue.
   e. After the Strain reaches 1.5%, take off the extensometer. The test will keep going until the specimen breaks.
   f. After the specimen breaks, input the value of the deformed gage length in the message box. Loosen the jaws from the control unit and retrieve the specimen. Measure the new gage length and enter the value in the message box. Also, measure the new thickness and width.
6. Click on "Print" tab and save the plot as a PDF file.

Raw Material Properties:

Raw material is provided in the form of a filament spool that is used by a 3D printer to print the tensile testing specimens. The *isotropic* properties of the material ABS are given below:

Young's Modulus = 2200 MPa (320,000 psi)
Yield Strength = 31 MPa (4,550 psi)

Ultimate Tensile Strength = 33 MPa (4,700 psi)

Specimen Dimensions:

0° : b = ______ in t = ______ in
45° : b = ______ in t = ______ in
vertical: b = ______ in t = ______ in

where ‘b’ is the width and ‘t’ is the thickness of the specimen cross section within the gage length area.

Required:

1. Plot the Stress vs. Strain curves for the three specimens in the same graph. **Note:** On your excel datasheets, convert the Force(lbs) to Stress(psi) by dividing the force with area. Convert the Position(in) to Strain(in/in) by dividing the position with the gage length (2 inches).
2. Calculate the Young’s modulus (psi) of each specimen from the three curves plotted in Task 1. Convert the value into MPa (1 psi=6.894 KPa). Identify the Tensile Strength (lbs) of the specimens from your data. Present the results in a tabular format. **Note:** Young’s modulus is the slope of the linear region of the plots from the Task 1. First 20 data points are enough to get the slope of the linear region.
3. Discuss the effect of the fiber orientation on the Young’s moduli and the shape of failure region. Sometimes, the specimens fail outside the gage length and in the neck region of the specimen. What are the possible reasons for this kind of behavior?
4. Consider a specimen P1 with the unidirectional strands laid at 0^0 to the length of the specimen and a specimen P2 with unidirectional strands laid at 90^0 to the length of the specimen (refer to the below picture). How will the tensile strengths of the specimens P1 and P2 compare to the specimens you tested for this experiment?

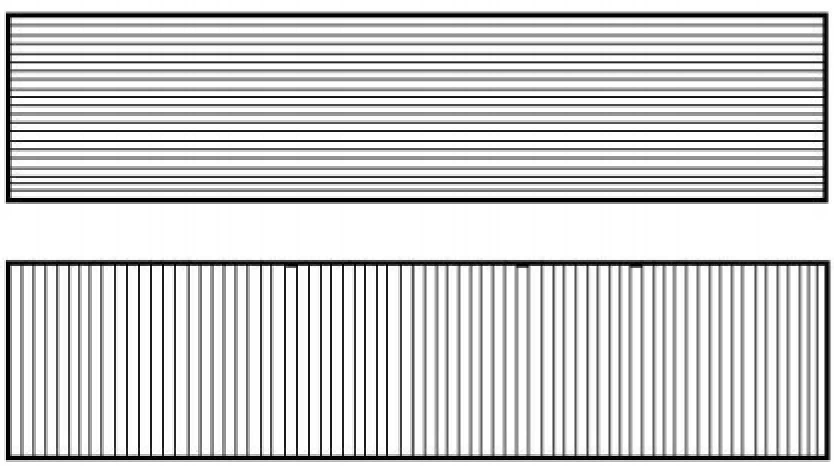


Figure: Raster orientation directions, 0° (top), 90° (bottom)

Lab 5: Determination of Modulus of Elasticity and Poisson's Ratio

Objective:
To determine the Modulus of Elasticity and Poison's ratio of Steel, the specimen being a member in tension, and compare them with theoretical values.

Theory:
1. Modulus of Elasticity
Modulus of elasticity (E) of a material is determined by the slope of the straight-line potion of its stress strain curve. It is the ratio of change of stress to the corresponding change of strain. E is a definite property of a material and is an index of the stiffness of that material. It means that a material having a higher slope on its stress-strain curve will be stiffer and will deform less under load than a material having a smaller slope.

For the stress-strain curve shown below in Fig 1, the modulus of elasticity is defined as the slope of the linear portion of the curve.

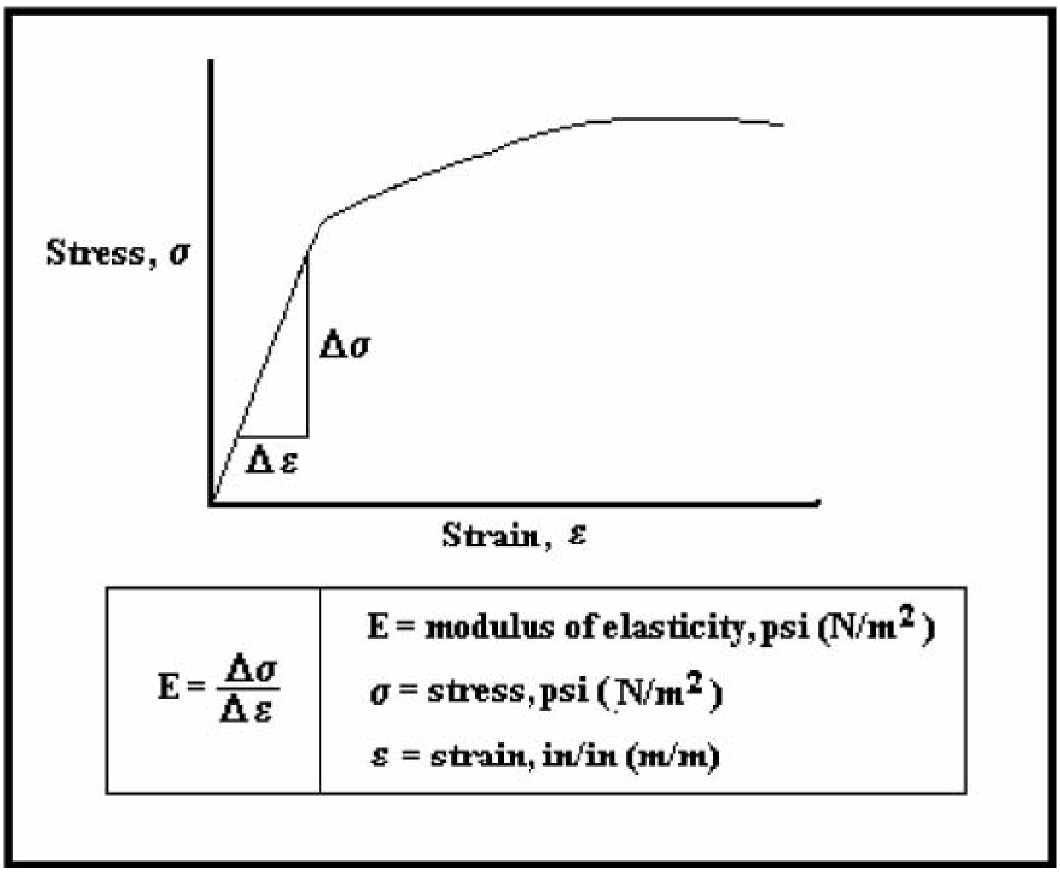


Fig 1 - Stress-Strain Diagram showing Modulus of Elasticity

Poisson's Ratio:
Modulus of Elasticity and Poisson's Ratio are the two material constants relating stress to strain in a biaxial stress field in the linear region. When an isotropic elastic material is subjected to uniaxial stress, while it deforms in the direction of the stress, it also exhibits a deformation of the opposite sign in the perpendicular direction. Poisson's Ratio is the absolute value of the ratio of transverse strain to the axial strain in a uniaxially stressed member (Fig 2).

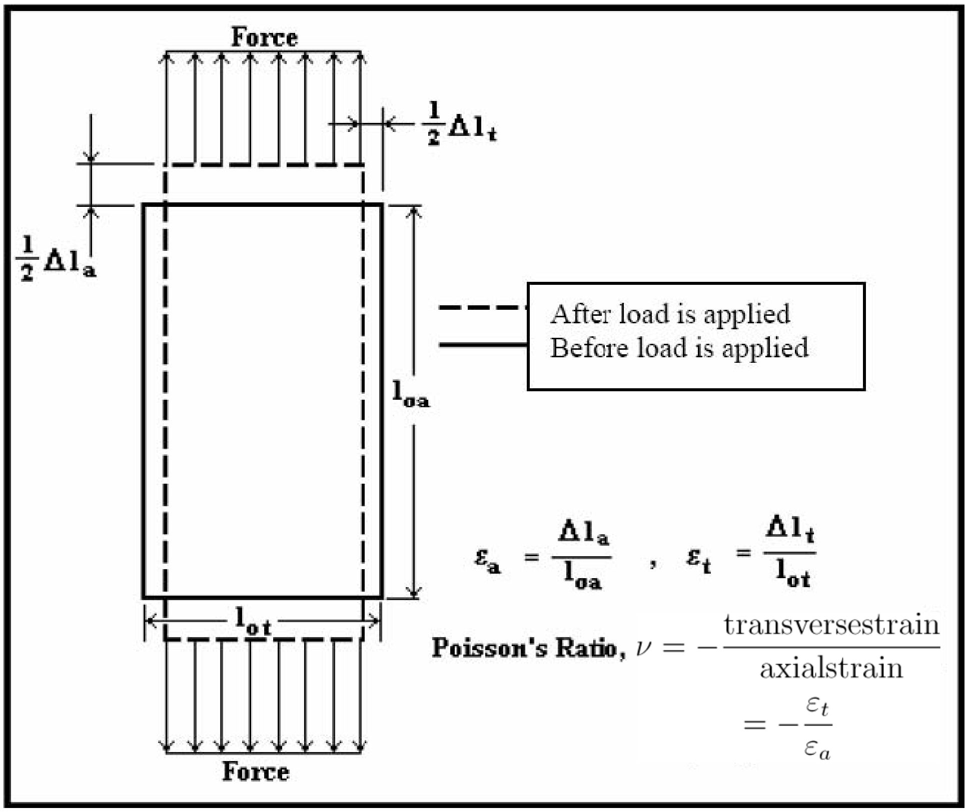


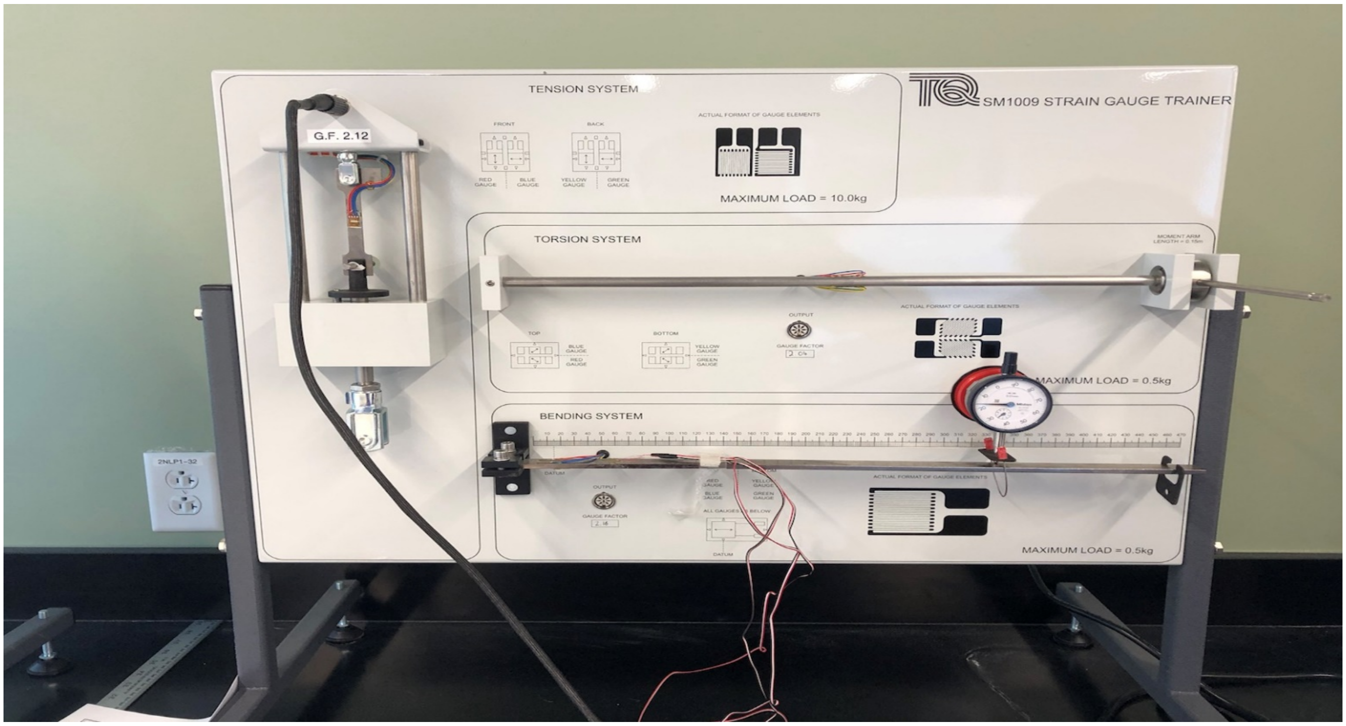
Fig 2 - Poisson's Ratio

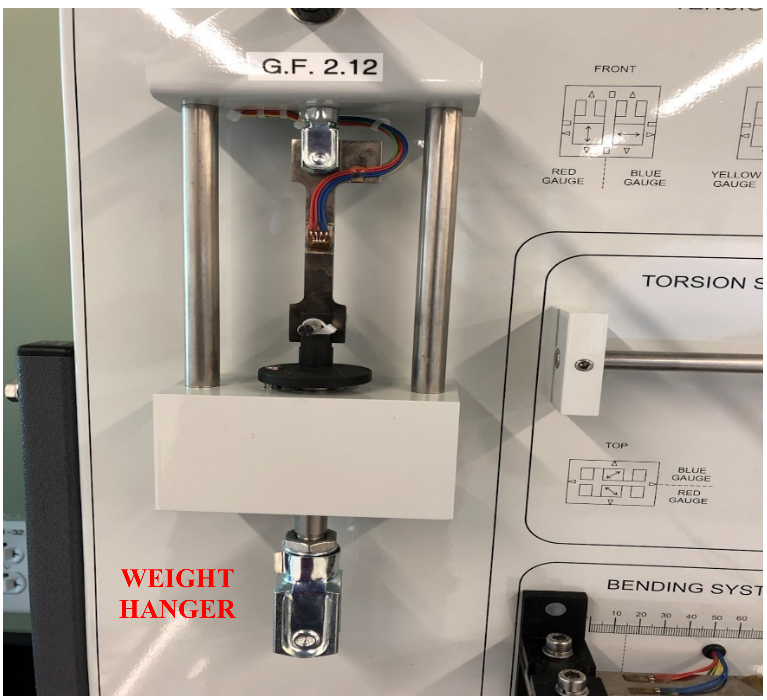
Experiment:

A member in tension (dog-bone) is a common structural element. Examples include tire rods. In this experiment the modulus of elasticity of a material will be determined.

A member under tension with a strain gauge attached in the axial direction on the top of the member and a strain gauge attached on the bottom of the member in the transverse direction can be used to determine the Poisson's ratio of a material. A constant cross-section member loaded statically may be used. The stress in the member under tension is uniaxial everywhere on the surface except in the immediate vicinity of the load. The absolute value of the ratio of the experimental values from the transversely oriented gauge to the values from the axially oriented gauge will give an experimental Poisson's Ratio.

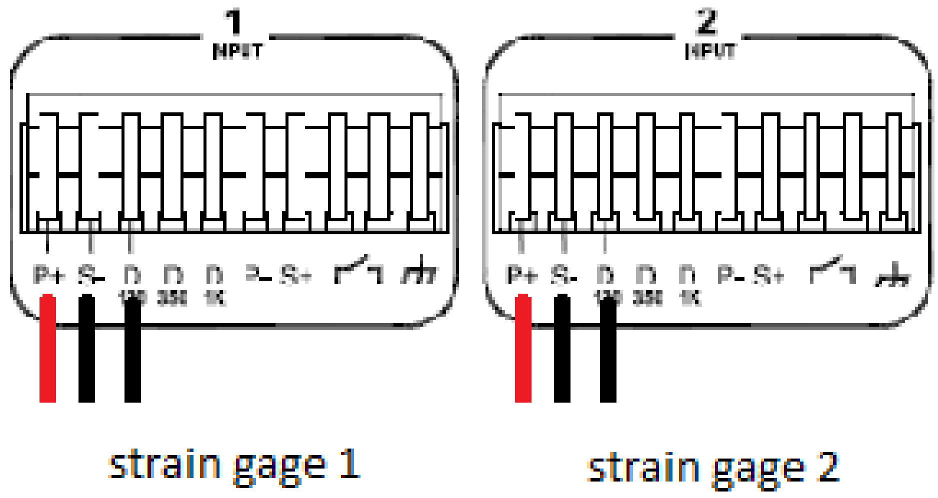
Experimental Setup:





Connections:

1. The connections between strain indicator and balance unit are as the below picture,
2. Strain gage #1 (on top of the beam) goes to Channel 1.
3. Strain gage #2 (on bottom of the beam) goes to Channel 2.



Strain Indicator Setup

1. Set the "**CONFIG**" to "2" to show the half-bridge configuration.
2. Set the "**GAUGE FACTOR**" to "**2.12**".
3. Press and hold "**ZERO**" to make the strain and voltage values set to zero.
4. Place the weights on the **"WEIGHT HANGER**"
5. Add weights and take down the strain reading. (NOTE: Take two readings. The first reading taken in above configuration shown in the picture would give the longitudinal strain reading. Take the lateral strain reading by switching the dummies with blue and green leads and plugging the dummies into the red and yellow leads. The readings are in $\mu\varepsilon$, $1\mu\varepsilon = 1\times 10^{-6}\varepsilon$).

Data Sheet:

1. Material: Steel
2. Theoretical Modulus of Elasticity: E = 28*10^{6} psi or 29*10^{6} psi / 193 or 200 GPa
3. Theoretical Poisson's Ratio, ν = 0.27 or 0.32
4. Gauge factor of the gauge = 2.12

Specimen Dimensions:

b = ______ *mm*   t = ______ *mm*   L = ______ *mm*

where
b=width,
t=thickness
L=effective length (distance between the gage centerline and the free end)

Observation Table:

Take readings for four different loads. Increase the mass in steps of 0.5kg. Remember all the strain values are in micro strain.

Mass (kg)	Load (N)	Stress (N/mm^2)	Experimental Longitudinal Strain $\varepsilon_{long-exp}$ ($\mu\varepsilon$)	Experimental Lateral Strain $\varepsilon_{lat-exp}$ ($\mu\varepsilon$)	Poisson's Ration (ν)
0.5					
1.0					
1.5					
2.0					
				Average:	

Calculations:

$$E = \frac{\Delta\sigma}{\Delta\varepsilon} = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - \varepsilon_1}$$

$$\nu = \frac{-\varepsilon_{lat}}{\varepsilon_{long}}$$

where,
P = load, lb. (N)
A = b*t = Cross-sectional area of the member
L = effective member length, that is, length from gauge centerline to applied load, in (mm)
b = beam width, in. (mm)
t = beam thickness, in. (mm)

Required:

1. Plot the stress (σ) vs. the longitudinal strain ($\varepsilon_{long-exp}$). Also plot the stress (σ) vs. the negative lateral strain ($-\varepsilon_{lat-exp}$) in the same graph. Determine the experimental Modulus of Elasticity (E) from the slope of the first plot. Find the average value of Poisson's ratio (ν) from the observation table above.
2. Compare the experimental values of Modulus of Elasticity & Poisson's ratio with the published ones for the steel member.
3. Quantify the errors and discuss the results.

1. **Graph of stress (σ) vs. longitudinal strain ($\varepsilon_{long-exp}$) and stress (σ) vs. negative lateral strain ($-\varepsilon_{lat-exp}$)**

Plot these graphs with the data from the observation table.

2 & 3.

			Experimental Results				Theoretical Values		Error (%)	
Mass (kg)	Load (N)	Stress (MPa)	Exp. Long. Strain $\varepsilon_{long\text{-}exp}$ ($\mu\varepsilon$)	Exp. Lat. Strain $\varepsilon_{lat\text{-}exp}$ ($\mu\varepsilon$)	Young's Modulus (E)	Poisson's Ration (ν)	Young's Modulus (E)	Poisson's Ration (ν)	E	ν
0.5										
1.0										
1.5										
2.0										
				Average:				Average:		

Note: $1\mu\varepsilon = 1\times10^{-6}\varepsilon$

Lab 6: Torsion Tests

Objective:
To determine Shear Modulus of Elasticity (G) of Steel and develop a relationship among the torque (T), the clamping length (L) and the angle of twist (θ).

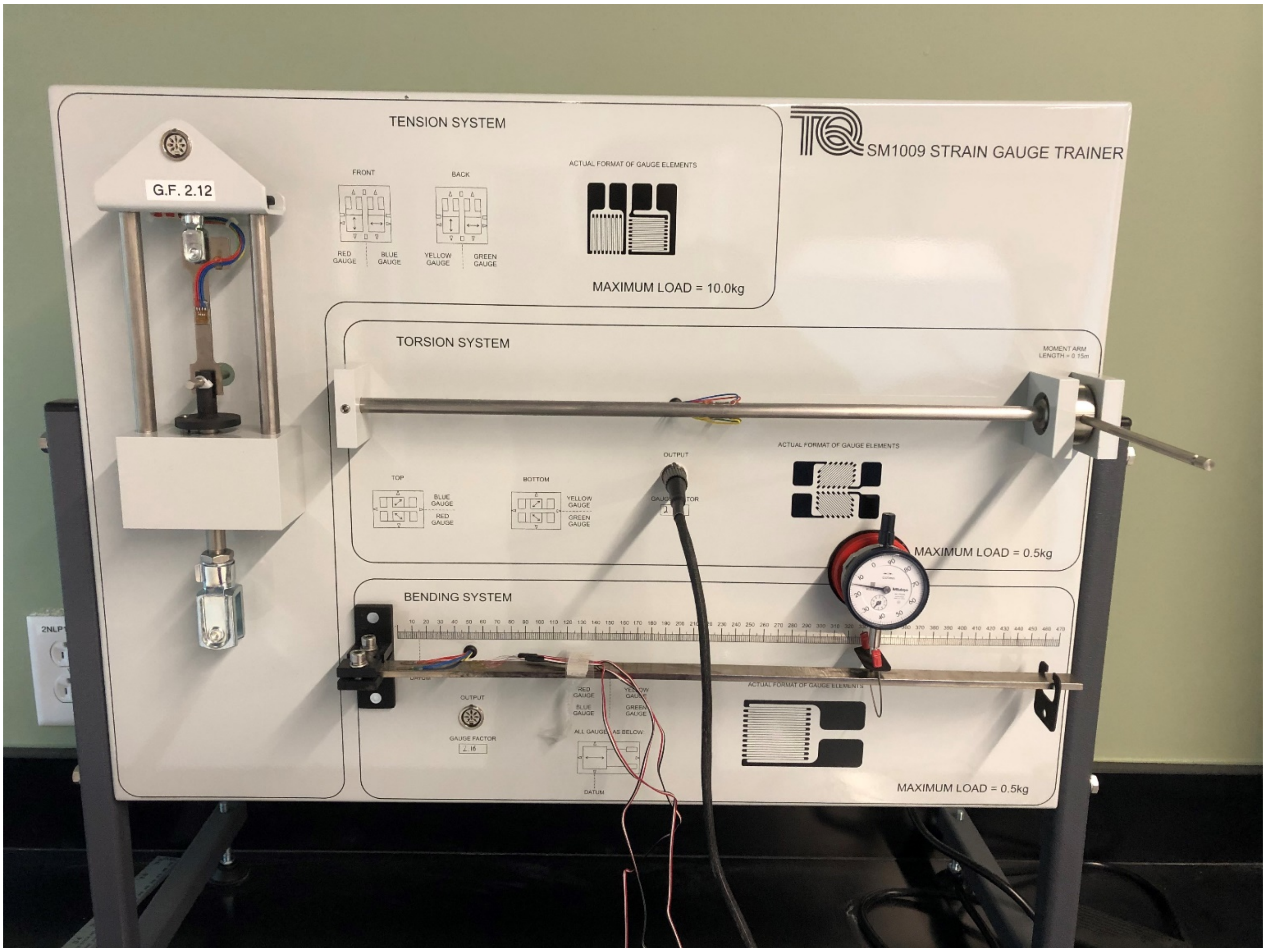


Fig 1 - Torsion Test

Experiment:
Two twist and bend shaft (shown above in Fig 1) used to find the Shear Modulus of Elasticity of Steel. The specimen is cylindrical.

Procedure:
Following are the three tasks to be performed on the steel shaft.

1. Develop a relationship between torque and angle of twist:
The following is the step by step procedure to be followed for the experiment:

1. Set **Config** knob to **4** for full bridge on the Digital Strain Display (Wheatstone bridge). **"Act"** on the display shows the active arms of the Wheatstone bridge.
2. Insert the leads as shown in the figure below.
3. Look at the Torsion equipment and the **Gage factor** mentioned is 2.04. Set this value on the Digital Strain Display by the knob.
4. Hold **"ZERO"** for couple of seconds to make the values of strain and voltage to zero.
5. Start loading the mass on the holding rod and measure the strain values.

Steel

Mass (kg)	Strain (με)
0.25	
0.5	
0.75	
1.0	
1.25	
1.5	
1.75	
2.0	

2. Determine the shear modulus and torsional stress for steel
Use the readings taken above to calculate shear modulus and torsional stress for Steel, using the formulae given below. Compare the experimental results with the theoretical values.

1. $T = P \times l = m \times g \times l$
2. $\tau = \frac{Tc}{J}$ where, $J = \frac{\pi c^4}{2}$
3. $\varepsilon = \frac{\gamma}{2}$ => $\gamma = 2\varepsilon$
4. $\gamma = \frac{\varphi c}{L}$ => $\varphi_{exp} = \frac{\gamma L}{c}$
5. $G_{exp} = \frac{TL}{J\varphi_{exp}}$ [Compare the G_{exp} VS G_{th} for all steels, obtained from the book and find error]

3. Determine the angle of twist
Find φ based on theoretical values of G_{th} mentioned in the book,
6. $\varphi_{th} = \frac{TL}{JG_{th}}$ [Compare the φ_{exp} VS φ_{th} and plot φ_{exp} VS φ_{th}]
where,
T = Torque (N-mm)
L = Span Length (mm)
J = Polar Moment of inertia of the specimen (mm^4)
d = Diameter of the specimen (mm)
φ = Angle of twist (radians)
c = distance from the center of the specimen (mm), Note: for outer surface, c=radius of the specimen
G = Shear Modulus of Elasticity (N/mm^2)
P = Load (N)
m = mass (kg)
l = length measured from the center of the strut to the **dent where the weight is applied** (mm)

Datasheet:
Theoretical values of shear modulus of elasticity
Steel, G = 80 GPa

Specimen Dimensions:

Steel:	D_0 =	______ *mm*	J =	______ mm^4
Aluminum:	D_0 =	______ *mm*	J =	______ mm^4

where D_0= diameter of the specimen, J= polar moment of inertia

Required:

1. Plot a graph of T VS φ_{exp} for steel.
2. Plot a graph of φ_{exp} VS φ_{th}
3. Determine shear modulus of elasticity (G) and torsional shear stress (τ) on the top surface using data from task 1 and formulae 2 to 5, for steel. Hint**:** Determine G from the slope of the curve obtained in Task 1.
4. Compare the calculated values of G with the theoretical value and quantify the errors.
5. **The x and y axes must be appropriately labeled. Mention the scale and units of measurement on the graph.**

Plot: T VS φ

Plot: φ_{exp} VS φ_{th}

Lab 7: Stress Concentration

Objectives:

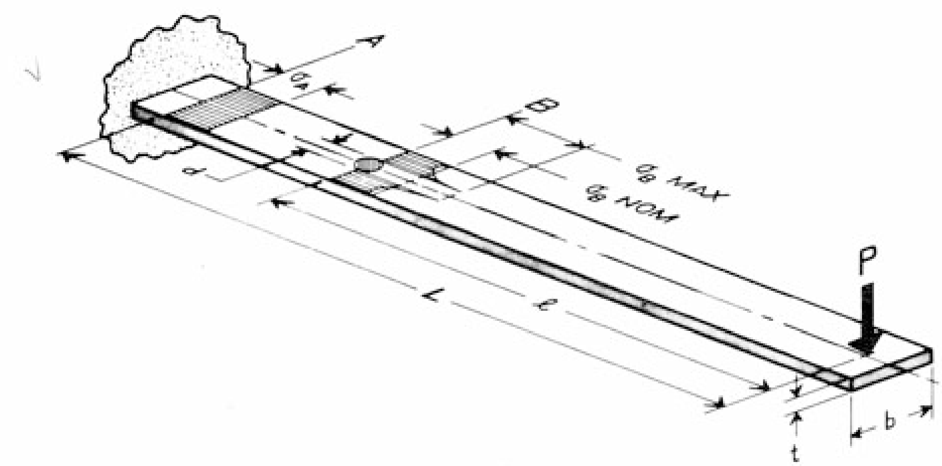
(1). To understand the importance of stress concentration and to determine the stress concentration factor for an aluminum cantilever beam that has a hole in it.

(2). To plot the strain distribution in the vicinity of the hole for different loads.

Theory:

Stress concentration is caused by the presence of any geometric irregularity in the shape of a loaded mechanical part or structural member. The trajectories of the stress are impeded, causing them to crowd together and thus increasing the stress above the nominal stress level (Fig 1). Closer the discontinuity, higher is the stress level, while the stress level is closer to the nominal level as we move farther away from the discontinuity. These higher stresses must be considered while designing the member.

The presence of stress concentration generally means that the sample is more likely to fail in the area around it because of, well, the higher concentrated stress. To consider the effect of stress concentration, a factor called the stress concentration factor K_t is introduced. It is defined as **the ratio of maximum stress to nominal stress**. K_t includes the effects of removal of the material and discontinuity. It depends on the geometry of the member in the vicinity of the discontinuity.



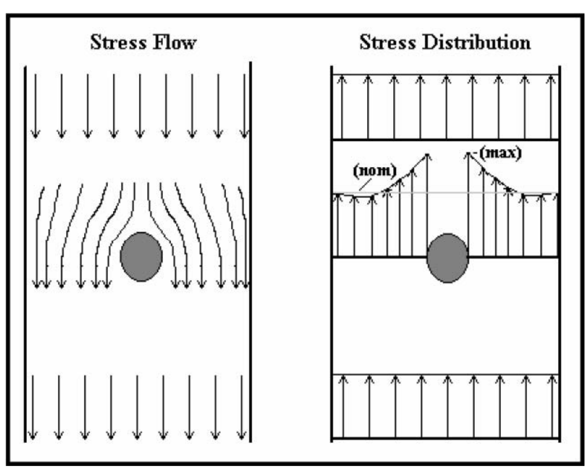


Fig 1 - Stress flow and stress distribution around a discontinuity

Experiment:

An aluminum cantilever beam, which has a hole in it, is subjected to a point load at its free end. The beam has a constant cross-section in all areas except where the **hole** is present and the stress is uniaxial everywhere on the beam surface except in the immediate vicinity of the load and the area around the hole.

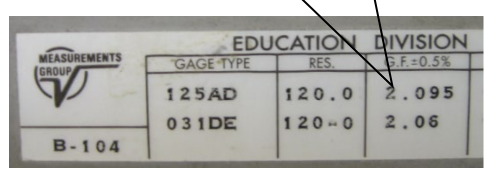
The stress distribution due to stress concentration around a discontinuity can be determined by reading the strain at several known distances from the geometric discontinuity. The nominal stress is the average stress at the cross-section. **The maximum stress divided by the nominal stress will give an experimental stress concentration factor. Since the nominal stress at both sections of the beam, and the peak stress at the edge of the hole, are all uniaxial, the strain and stress are proportional, if the proportional limit of the beam is not exceeded (as in our case) in the experiment. Thus, the stress concentration factor is equal to the ratio of the maximum to nominal strains at section B.**

DAQ and LabView VI setup

1. Insert the NI 9219 module into DAQ. Connect DAQ to the computer using the USB cable.
2. Connect one strain gauge to the Channel 0 (ai-0) at pin 3 (red wire) and 5 (white wire). This is the quarter bridge connection. Refer to NI 9219 module – Getting Started Guide, Page 12.
3. Open the LabView VI. Make sure to set the correct Gauge Factor in the VI for the strain gauges used in the experiment.
4. Run the VI to take the strain reading with no load on it. Copy the strain reading and paste it into the ZERO reading and enter. This is done to zero out the readings for the reference point.
5. Add weights and note down the strain readings. Add first weight of 0.5 kgs on the point of discontinuity (hole) on the beam. This will record the first strain reading. Keep adding the weights in 0.5 kg increments up to 2 kgs and record each strain reading.
   NOTE that the reading is in $\mu\varepsilon$, $1\mu\varepsilon = 1\times10^{-6}\varepsilon$)

Data Sheet
Material: Gauge Data:
Theoretical Poisson's Ratio, ν: 0.33
Theoretical Modulus of Elasticity, E: $10*10^6$ psi or 69 GPa
Theoretical Stress Concentration Factor, K_t: 1.768
Gage Factor, gauge 1: _________
Gage Factor, gauge 2: _________
Gage Factor, gauge 3: _________
Gage Factor, gauge 4: _________

Gage Factors are labeled on the specimen.
Gage #4: 125AD
Gage #1~#3: 031DE



Specimen Dimensions:

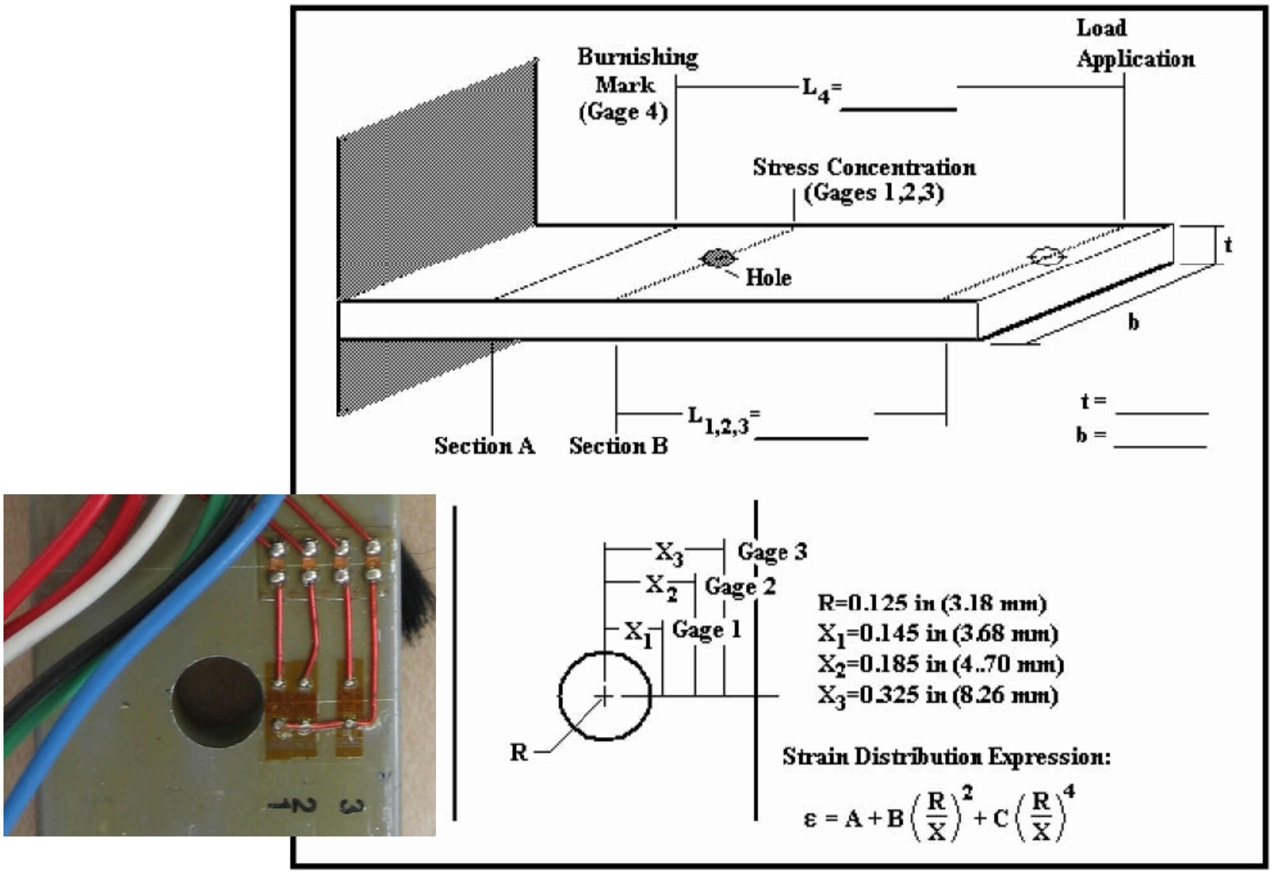


Fig 2 - Experimental setup to find stress concentration factor

b = ______ *mm* t = ______ *mm* $L_{1,2,3}$ = ______ *mm* L_4 = ______ *mm*

where b=width of the specimen
t=thickness of the specimen
$L_{1,2,3}$= Distance from the dent to the section B
L_4= Distance from the dent to the section A

Theoretical Calculations:

Computation of Nominal Stresses from the Flexure Formula:

Section A:

$$\sigma_{A(nom)} = \frac{Mc}{I} = \frac{6PL_4}{b_1 t^2}$$

$$\varepsilon_A = \frac{\sigma_A}{E}$$

Section B:

$$\sigma_{B(nom)} = \frac{Mc}{I} = \frac{6PL_{1,2,3}}{b_2 t^2}$$

where,
M = bending moment at gauge centerline, lbs-in (N-mm)
c = semi-thickness of beam, in (mm)
I = moment of inertia of beam cross section, $in^4 (mm^4)$
P = load, lbf. (N)
$L_{1,2,3}$= distance from the dent where load is applied to the section B, in(mm)
L_4= distance from the dent where load is applied to the section A, in(mm)
b_1 = beam width, in (mm)
b_2 = (beam width – hole diameter), in (mm)
t = beam thickness, in (mm)
d = hole diameter, in (mm)
E = Young's modulus of Aluminum = 69,000 MPa

Note:

$\sigma_{A(nom)} = \sigma_{B(nom)}$ when $\frac{L_{1,2,3}}{L_4} = \frac{b-d}{b}$

Observation Table:

Mass (Kg)	Experimental			
	ε_1 ($\mu\varepsilon$)	ε_2 ($\mu\varepsilon$)	ε_3 ($\mu\varepsilon$)	ε_4 ($\mu\varepsilon$)
0.5				
1.0				
1.5				
2.0				

Formulae and Calculations♠:
1. Computation of Coefficients for Extrapolation

$$C = 5.86 * (\varepsilon_1 - \varepsilon_2) - 5.44 * (\varepsilon_2 - \varepsilon_3)$$
$$C = 5.86 * (\_\_\_\_\_\_\_ - \_\_\_\_\_\_\_) - 5.44 * (\_\_\_\_\_\_\_ - \_\_\_\_\_\_\_) = \_\_\_\_\_\_\_$$

$$B = 3.49 * (\varepsilon_1 - \varepsilon_2) - 1.2 * C$$
$$B = 3.49 * (\_\_\_\_\_\_\_ - \_\_\_\_\_\_\_) - 1.2 * C = \_\_\_\_\_\_\_$$

$$A = \varepsilon_1 - 0.743 * B - 0.552 * C$$
$$A = \_\_\_\_\_\_\_ - 0.743 * \_\_\_\_\_\_\_ - 0.552 * \_\_\_\_\_\_\_ = \_\_\_\_\_\_\_$$

2. Maximum Strain (at edge of hole), ε_0

$$\varepsilon_0 = A + B + C$$
$$\varepsilon_0 = (\_\_\_\_\_\_) + (\_\_\_\_\_\_\_) + (\_\_\_\_\_\_\_) = \_\_\_\_\_\_\_\_$$

♠ Please refer *Appendix 1* at the end of this manual for a detailed discussion of the formulae used herein.

3. Experimental Stress Concentration Factor, K_t:

$K_t = ((\varepsilon_0 / \varepsilon_4) = (\_\_\_\_\_\_) / (\_\_\_\_\_\_) = \_\_\_\_\_\_)$

Computation Table:

Mass (kg)	Load (N)	C	B	A	Maximum Strain ε_0 (με)	Nominal Strain ε_4 (με)	Stress Conc. factor K_t
0.5							
1.0							
1.5							
2.0							

Summation Table:

		Theoretical				Experimental			% Error	
mass	Load (N)	Nominal Stress		Nominal Strain	Stress Conc. factor	Nominal Strain	Maximum Strain	Stress Conc. factor	Nominal Strain	Stress Conc.
		σ_A	σ_B	ε_A	K_t	ε_4	ε_0	K_t		
(kg)		(MPa)	(MPa)	(με)	---	(με)	(με)	---	(%)	(%)
0.5					1.768					
1.0					1.768					
1.5					1.768					
2.0					1.768					

Required:

1. Experimental values of K_t. Your values are consistent but probably considerably smaller than the theoretical value. Discuss possible causes.
2. Average % error for experimental stress concentration factor K_t and nominal strain when compared with theoretical values.
3. Plot the strain distribution (Strain vs Distance) using the experimental strains $\varepsilon_1, \varepsilon_2, \varepsilon_3$ in the observation table and distances X1, X2 and X3 from the appendix. Comment on the shape of the strain distribution.

Appendix A (Lab 7: Stress Concentration)

Stress Concentration (Analysis and Presentation of Data)[♠]

The actual strains in the region of stress concentration will be measured with three very small strain gauges placed in the section B at varying distances from the edge of the hole, with one of gauges directly adjacent to the edge. The strains indicated by the three gauges will be plotted on a graph sheet at the locations of the respective gauge centerlines. A smooth curve can be drawn through the resulting three data points to show the strain distribution in the vicinity of the hole. Since the centerline of the closest gauge to the hole cannot physically coincide with the edge of the hole, it is necessary to extrapolate the data to the edge to obtain an approximate value for the maximum strain. Extrapolation can be done "by eye" or, more objectively, by the algebraic technique given below.

It is not unreasonable to assume that the strain distribution can be represented approximately by an expression of the following form:

$$\boldsymbol{\varepsilon = A + B*(R / X)^2 + C*(R / X)^4}$$

where **R** is the radius of the hole, **X** is the distance from the center of the hole to any point on the transverse centerline, and **A**, **B** and **C** are the coefficients to be determined from the measured strains at three different points along the transverse centerline. Thus,

$$\boldsymbol{\varepsilon_1 = A + B*(R / X_1)^2 + C*(R / X_1)^4}$$

$$\boldsymbol{\varepsilon_2 = A + B*(R / X_2)^2 + C*(R / X_2)^4}$$

$$\boldsymbol{\varepsilon_3 = A = B*(R / X_3)^2 + C*(R / X_3)^4}$$

Noting that:

R = 0.125 in *(3.18 mm)*; $\mathbf{X_1}$ = 0.145 in *(3.68 mm)*; $\mathbf{X_2}$ = 0.185 in *(4.70 mm)*; $\mathbf{X_3}$ = 0.325 in *(8.26 mm)*

And solving the above simultaneous equations for **C**, **B** and **A**,

$$\mathbf{C} = 5.86 * (\boldsymbol{\varepsilon_1} - \boldsymbol{\varepsilon_2}) - 5.44 * (\boldsymbol{\varepsilon_2} - \boldsymbol{\varepsilon_3})$$

$$\mathbf{B} = 3.49 * (\boldsymbol{\varepsilon_1} - \boldsymbol{\varepsilon_2}) - 1.20 * \mathbf{C}$$

$$\mathbf{A} = \boldsymbol{\varepsilon_1} - 0.743 * \mathbf{B} - 0.552 * \mathbf{C}$$

Substituting the measured strains from the table into the first equation of the above three gives **C**, which can then be substituted into the next equation with the strains to obtain **B**, etc.

Since **R / X** = 1 at the edge of the hole,

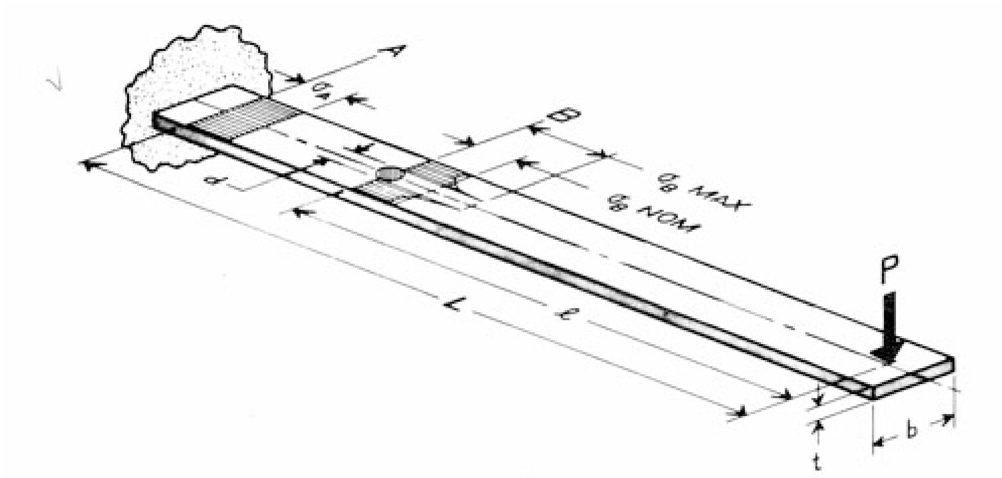
$$\boldsymbol{\varepsilon_0} = \mathbf{A} + \mathbf{B} + \mathbf{C} \text{ (peak strain)}$$

[♠] The text for stress concentration is a reproduction from the manual *E-104 Stress and Strain Concentration* which accompanies the pre-gauged beam *B-104* manufactured by *Measurements Group*.

The strain (and stress concentration factor is then:

$K_t = \varepsilon_0 / \varepsilon_4$

where: ε_4 = the strain indication at gauge 4.



For this Lab, the specimen has,

d(hole diameter)=0.25in
b(width)=1in
h(thickness)=0.25in

$$K_{tn} = \frac{\sigma_{\max}}{\sigma_{nom}} = C_1 + C_2(\frac{d}{b}) + C_3(\frac{d}{b})^2$$

$$C_1 = 1.82 + 0.3901(\frac{h}{d}) - 0.01659(\frac{h}{d})^2$$

$$C_2 = -1.9164 - 0.4376(\frac{h}{d}) - 0.01968(\frac{h}{d})^2$$

$$C_3 = 2.0828 + 0.643(\frac{h}{d}) - 0.03204(\frac{h}{d})^2$$

Theoretical Kt of this specimen is around **1.768**

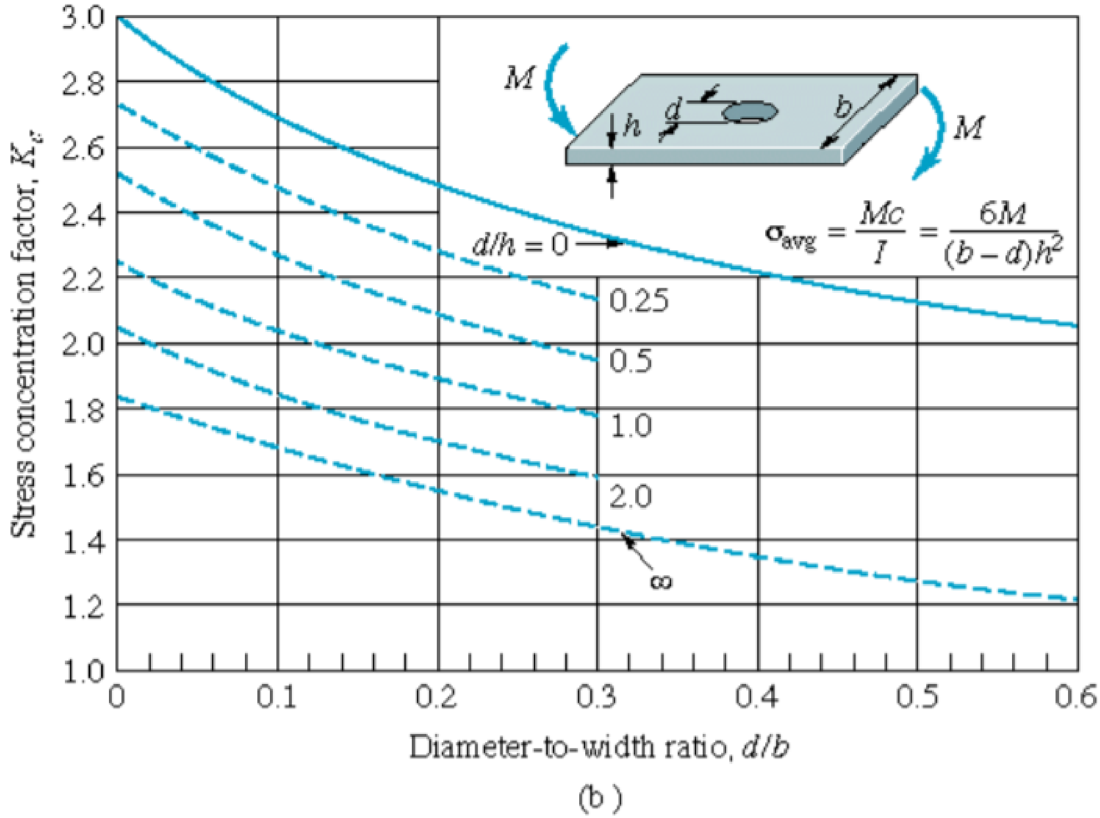
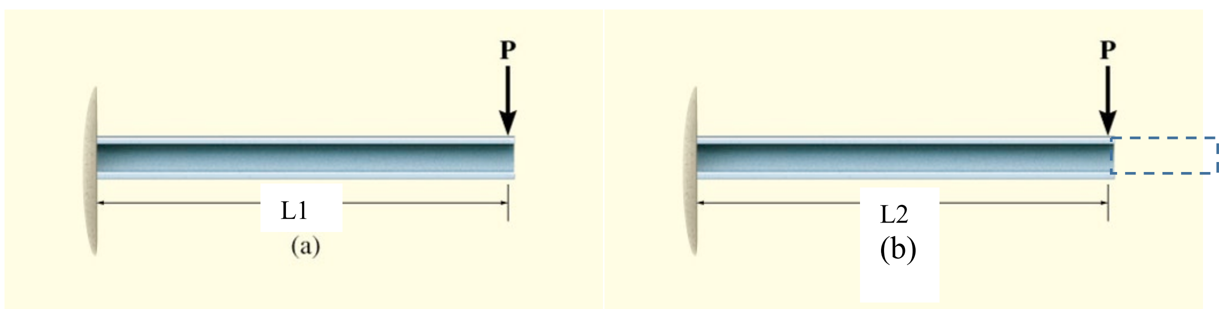


Figure: Simple Bending- Stress Concentration factor for a beam with a hole

Lab 8: Cantilever Beam Bending Test

Objective:
To understand the importance of beam deflection and perform a cantilever loaded bending test on a steel beam.

Theory:
The axis of a beam deflects from its initial position under the action of applied loads. Accurate values of these beam deflections are sought in many practical applications, e.g., elements of machines must be of sufficient rigidity to prevent misalignment and to maintain dimensional accuracy under load; in buildings, floor beams cannot deflect excessively to avoid the undesirable physiological effect of flexible floors on occupants and to minimize or prevent distress in brittle-finish materials. Likewise, information on deformation characteristics of members is essential in the study of vibrations of machines as well as of stationary and flight structures. Deflections are also used in analyses of statically indeterminate problems. In short, an understanding of how to compute beam deflections is important.



For a fixed cantilever supported beam with a point load P, deflection in the linear elastic region at the end of the beam is given by:

$$\boxed{\delta \text{ at } L = \frac{F(L)^3}{3\,EI}} \qquad \text{(a)}$$

where,
F = load
L= distance between fixed support and the free end support
E= modulus of elasticity
I= second moment of area of cross section = $bt^3/12$
b= width of the bar
t= thickness of the bar

The deflection in the above equation depends on the load being applied, the span length, Young's modulus and second moment of area. The product EI in the denominator is called as *flexural rigidity* or *beam stiffness*. Flexural rigidity is defined as the resistance offered by a structure when it is under a bending load.

Experiment

A. TQ SM1009 Strain Gauge Trainer Test.
TQ SM1009 Strain Gauge Trainer is used to apply a controlled load on a specimen slowly and steadily, thereby bending it.

Procedure
There are four steps involved in this test. Prepare the specimen, set the test parameters, run the test, collect the load-deflection data and evaluate the experimental results.

Specimen Preparation:
Measure the width and thickness of the specimen. Draw a line at the center of the specimen.

Running the test and collecting the data:

1. Load the beam at full length of the beam.
2. Zero out the manual strain gauge read out dial.
3. Prepare slide weights and hanger rod for a total of _______________kg. (Mass). Use W=F=mg to find the load in Newtons.
4. Initialize the experiment – load weights at 10 g (force) at a time and take the appropriate resulting strain readings from the strain gage read out per each load weight step. Repeat this process 10 times while remaining in the elastic range of the specimen material.

Required:
Each group is required to submit the following for both the test specimen(s):

1. Calculate the theoretical deflection values by using the formula (a) by using the load values. Compare the theoretical deflection VS the deflection values obtained through the experiment and justify the error.
2. Plot experimental "Load (lbs) vs. Strain (in)" curve. Use excel to plot this curve using the data collected from the experiment. (Note: Use the data column - FORCE and the data column STRAIN to plot the curve,)

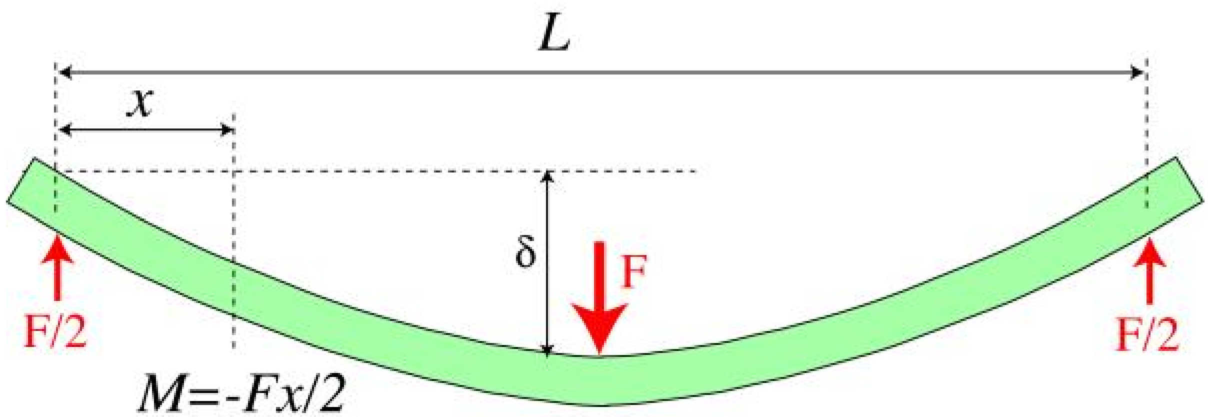
3. On the same graph, using Eq.1, plot a theoretical "load vs. deflection" curve in the linear elastic region. Take E_{steel} = 29 x 10^6 psi = 200 GPa and E_{brass} = 16 x 10^6 psi = 110 GPa. Compare the slope of the theoretical curve (using the below equation) with that of the experimental curve and quantify the error. Justify the error. (**Note**: calculate the slope of linear elastic region only)
$$slope = \frac{\Delta P}{\Delta y} = \frac{3EI}{L^3}$$
4. Identify the maximum load on the experimental "Load vs Strain" curve.
5. Calculate the value of the theoretical and experimental beam stiffness
   a) Theoretical beam stiffness = EI,
   b) Experimental beam stiffness is calculated from the above-mentioned formula but using the experimental deflection values.

Data sheet:
Specimen Dimensions:
Steel: b = ______ mm t = ______mm L = ______mm I = ______ mm^4 or m^4

Lab 9: 3-Point Bending Test

Objective:
To understand the importance of beam deflection and perform a 3 point-bending test on a steel and a brass beam.

Theory:
The axis of a beam deflects from its initial position under the action of applied loads. Accurate values of these beam deflections are sought in many practical applications, e.g., elements of machines must be of sufficient rigidity to prevent misalignment and to maintain dimensional accuracy under load; in buildings, floor beams cannot deflect excessively to avoid the undesirable physiological effect of flexible floors on occupants and to minimize or prevent distress in brittle-finish materials. Likewise, information on deformation characteristics of members is essential in the study of vibrations of machines as well as of stationary and flight structures. Deflections are also used in analyses of statically indeterminate problems. In short, an understanding of how to compute beam deflections is important.



For a simply supported beam with a point load P, deflection in the linear elastic region at the center is given by:

$$\delta_{L/2} = -\frac{FL^3}{48EI} \tag{1}$$

where,
F = load
L= distance between two roller supports
E= modulus of elasticity
I= second moment of area of cross section = $bt^3/12$
b= width of the bar
t= thickness of the bar

The deflection in the above equation depends on the load being applied, the span length, Young's modulus and second moment of area. The product EI in the denominator is called as *flexural rigidity* or *beam stiffness*. Flexural rigidity is defined as the resistance offered by a structure when it is under a bending load.

Experiment

A. TQ TE16 Stiffness of Materials and Structures Experiment Test (TE16 Test)
TE 16 Test System applies a controlled load on a specimen slowly and steadily, thereby bending it. The user specifies test parameters such as type of test, units, preload, and deflection recorded by the dial gauge, records all of the testing process, including recording the applied load, deflection and the load-deflection data readings.

Procedure
There are five steps involved in this test. 1) prepare the specimen, 2) set the test parameters, 3) run the test, 4) collect the load-deflection data and 5) evaluate the experimental results.

Specimen Preparation:
Measure the width and thickness of the specimen. Draw a line at the center of the specimen.

Running the test and collecting the data:
1. Select an arbitrary span length on the TE16 Test assembly.
2. Place the beam on the on the supports (simply supported beam and adjust the dial gauge at the center. Also, zero the dial gauge.
3. Apply the load on the beam at the center.
4. Measure the experimental deflection values for increment of 10g for 10 readings.

Required:
Each group is required to submit the following for both the specimens:
1. Calculate the theoretical deflection values by using the formula (a) by using the load values. Compare the theoretical deflection VS the deflection values obtained through the experiment and justify the error.
2. Plot <u>experimental</u> "Load (lbs) vs. Deflection (in)" curve. Use excel to plot this curve using the data collected from the computer after the experiment. (Note: Use the data columns-FORCE and EXT to plot the curve, extension is the percentage of deflection, i.e., 1% =0.01 inches)
3. On the same graph, using Eq.1, plot a <u>theoretical</u> "load vs. deflection" curve in the linear elastic region. Take E_{steel} = 29 x 10^6 psi = 200 GPa and E_{brass} = 16 x 10^6 psi = 110 GPa.
4. Compare the slope of the theoretical curve (using the below equation) with that of the experimental curve and quantify the error. Justify the error. (**Note**: calculate the slope of linear elastic region only)

$$slope = \frac{\Delta P}{\Delta y} = \frac{48EI}{L^3}$$

5. Identify the maximum load on the experimental "Load vs Deflection" curve.
6. Calculate the value of the theoretical and experimental beam stiffness
    a. Theoretical beam stiffness = EI,

    c) Experimental beam stiffness= (slope from task #3) x (L^3/48) OR Experimental beam stiffness is calculated from the above-mentioned formula but using the experimental deflection values.

Data sheet:

Specimen Dimensions:
Steel: b = ______ mm t = ______mm L = ______mm I = ______ mm^4 or m^4

Lab 10: Thin-Walled Pressure Vessels

Objective: Stress and pressure analyses of a soda can (A thin-walled pressure vessel).

Theory:
Internal pressure causes stresses in the walls of pressure vessels. There are two types of pressure vessels, thick-wall pressure vessels and thin-wall pressure vessels. Most of the pressure vessels you will encounter in your career are likely to be of the thin-wall type. A vessel is thin-walled pressure vessel if it satisfies the following criteria.

$$\frac{D_m}{t} \geq 20$$

Where,

D_m = Mean diameter in mm
t = Thickness in mm

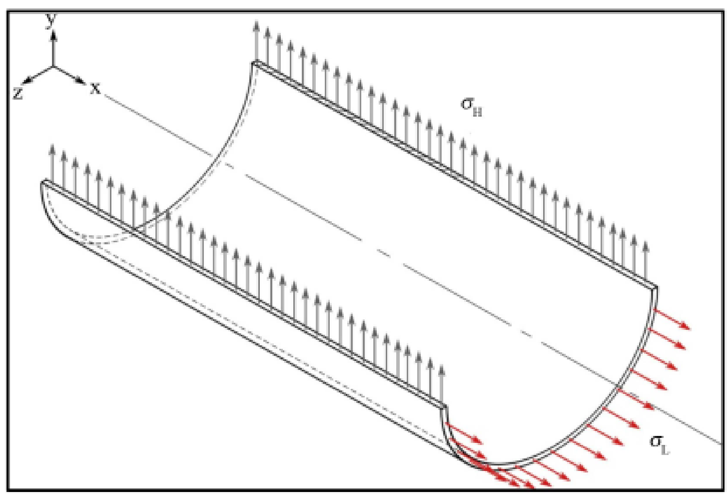
Cylinders are frequently used for pressure vessels; for example, as storage tanks, hydraulic and pneumatic actuators, and for piping of fluids under pressure. In this lab, we will do two separate analyses for a soda can, which is cylindrical in shape. In one case, the tendency for the internal pressure to pull the cylinder apart in a direction parallel to its axis is found. This is called ***longitudinal stress***. Next, a ring around the can is analyzed to determine the stress tending to pull the ring apart. This is called ***hoop stress, or tangential stress***. Theoretically, longitudinal stress and hoop stresses are given by:

Longitudinal Stress:

$$\sigma_L = \frac{pD_m}{4t} \qquad (1)$$

Hoop Stress:

$$\sigma_H = \frac{pD_m}{2t} \qquad (2)$$



where,
p -internal pressure (psi)
$D_m = D_o - t \simeq D_o$
D_o - outer diameter of the can (in.)
D_m -mean diameter of the can (in.)
t -wall thickness (in.)

Note that $\sigma_H = 2\sigma_L$ (3)

Experiment:
A soda can is analyzed as a thin walled pressure vessel. The pressure inside the soda can be determined by measuring the elastic strains that are induced on the can when the pressure is released by popping the can open. Basic Hooke's law stress and strain relations can be used to derive the internal pressure of the can.

Assuming the material is homogenous and isotropic, the pressurized can is under in the elastic deformed state, and a biaxial state of stress exists in the can, then the internal stresses developed in the soda can are proportional to the elastic strains of the outside surface of the soda can as follows:

$$\sigma_L = \frac{E(\varepsilon_L + \nu\varepsilon_H)}{1-\nu^2} \quad (4)$$

$$\sigma_H = \frac{E(\varepsilon_H + \nu\varepsilon_L)}{1-\nu^2} \quad (5)$$

where:

E - modulus of elasticity or Young's modulus (psi)

ε_H - hoop strain (in/in)

ε_L - longitudinal strain (in/in)

ν - Poisson's ratio

These relations along with (1) and (2) relate the hoop and axial strains to the internal pressure before the can was opened.

$$p = \frac{-4t\sigma_L}{D_m} \quad (6)$$

$$p = \frac{-2t\sigma_H}{D_m} \quad (7)$$

The internal pressure therefore can be calculated from the measured longitudinal or hoop strains.

Procedure:

A soda can with two strain gauges, one along the longitudinal direction and the other along circumferential direction will be tested for longitudinal and hoop strains, , for three scenarios:

1. Soda can full and closed
2. Soda can full and open
3. Soda can empty and open

Do not disturb the can as it might result in pressure variations and induce unwanted strains. What we are interested is to find the pressure inside the can in an undisturbed state.

DAQ and LabView VI setup

1. Insert the NI 9219 module into DAQ. Connect DAQ to the computer using the USB cable.
2. Connect one strain gauge to the Channel 0 (ai-0) at pin 3 (red wire) and 5 (white wire). This is the quarter bridge connection. Refer to NI 9219 module – Getting Started Guide, Page 12.
3. Open the LabView VI. Make sure to set the correct Gauge Factor in the VI for the strain gauges used in the experiment.
4. Run the VI to take the strain reading with the filled pressurized pressure vessel (coke can). Copy the strain reading and paste it into the ZERO reading and enter. This is done to zero out the readings for the reference point.
5. Open the coke can and note down the strain readings. Now empty the coke can and record the strain reading.
   NOTE that the reading is in $\mu\varepsilon$**,** $1\mu\varepsilon = 1\times10^{-6}\varepsilon$)

Data Sheet:
Thickness of the can, t = 0.004 in
Modulus of Elasticity, E = 10×10^6 psi
Poisson's Ratio, υ = 0.33

Specimen Dimensions:

D_m = ______ in

Observation:

ε_1 = _________ x 10^{-6} (longitudinal strain)
ε_2 = _________ x 10^{-6} (hoop strain)

Calculations:
Experimental longitudinal and hoop stresses can be calculated using (4) and (5).

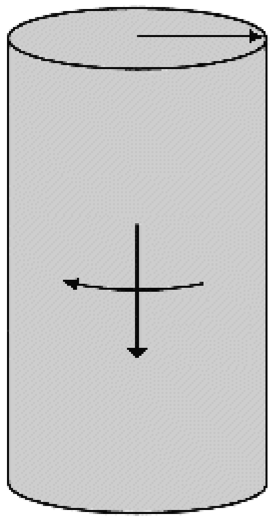
Pressure inside the can, can be calculated using the longitudinal or hoop strain from (6) and (7).

Required:

1. Why are the strain values shown on the strain gage indicator negative?
2. Calculate the longitudinal and hoop stresses. Find the ratio of the hoop stress to the longitudinal stress. According to the equation (3), theoretically, this ratio is equal to two. Calculate the error between the experimental and theoretical ratios. Justify the error.
3. Calculate the pressure using (a) longitudinal stress and (b) hoop stress. Clearly, these two values of pressure are supposed to be equal theoretically. What is the major cause of uncertainty between these two values, experimentally? (**Hint**: Look at the equations (6) and (7) and identify the parameter that can cause major uncertainty)
4. Derive an expression for Poisson's ratio (ν) in terms of longitudinal and hoop strains (ε_L & ε_H). Using this expression, calculate the Poisson's ratio for the experiment. Find error with respect to the published value, 0.33. (**Hint**: Use equations (3), (4), and (5) to eliminate σ_L and σ_H, and get a relation for ν in terms of ε_H and ε_L)

Appendix B (Lab 10: Thin-Walled Pressure Vessels)

A discussion about thin-walled pressure vessels♠



Internal pressure, p, acting directly on the wall of a cylindrical vessel with a circular cross section, produces a circumferential ("hoop") stress, σ_{MC}, in the wall. If the thickness of the wall, h, is small compared to the radius, r, of the cylinder:

$$\sigma_{MC} = \frac{pr}{h} \quad (1)$$

Accordingly, small pressures generate large hoop stresses in these thin-walled pressure vessels.

The pressure acting on the ends of the vessel also produces an axial ("longitudinal") stress, σ_{ML}, in the wall. If the length of the cylinder is large compared to the radius, the longitudinal stress away from the ends is half the hoop stress:

$$\sigma_{ML} = \frac{\sigma_{MC}}{2} = \frac{pr}{2h} \quad (2)$$

By using Hooke's law for isotropic materials in the linearly elastic range, the strains produced by these stresses can be expressed in terms of the geometry of the vessel, its mechanical properties, and the pressure of the fluid it contains:

$$\varepsilon_{MC} = \frac{(2-\nu)\sigma_{MC}}{2E} = \frac{(2-\nu)pr}{2Eh} \quad (3)$$

$$\varepsilon_{ML} = \frac{(1-2\nu)\sigma_{ML}}{E} = \frac{(1-2\nu)pr}{2Eh} \quad (4)$$

where E is the modulus of elasticity and ν is the Poisson's ratio of the vessel material. Unlike the materials-independent 2:1 ratio of stresses, the corresponding hoop strains are nearly five times larger than the longitudinal strains in vessels made of aluminum alloys having a Poisson's ratio of 0.33.

The preceding stresses and strains are either in the plane of, or tangent to, the cylinder wall. All have a positive sign (are "tensile") and each has the same magnitude at all points in the cylinder wall. Accordingly, these are "membrane" stresses and strains that produce increases in the length and circumference of the vessel under pressure. But, despite a change in the radius of curvature, the stresses remain uniform throughout the thickness of the wall and negligible bending moments are present.

♠ reproduced from the website *"http://www.vishay.com/brands/measurements_group/guide/notebook/e21/e21a.htm"*

Lab 11: Principal Stresses and Strains

Objective:

To determine principal stresses and strains in a beam made of aluminum and loaded as a cantilever, and compare them with theoretical values.

Theory:

For a general state of stress, principal stresses and planes are defined as follows:

Principal Stresses:

These are the normal stresses acting on planes of zero shear stress. For a general state of stress, there are three orthogonal principal stresses. The three principal directions for the principal stresses are orthogonal. The strains corresponding to principal stresses are called as principal strains. It is customary to order the principal stresses such that $\sigma_1 > \sigma_2 > \sigma_3$

Principal Planes:

Principal planes are the planes of zero shear stress. These planes are perpendicular to the principal directions i.e., directions along which the 3 principal stresses act.

Experiment:

A parallel-sided, constant cross-section cantilever beam with a rectangular rosette will be used to determine the principal strains. The stress in the beam is uniaxial everywhere on the beam surface except in the immediate vicinity of the load. Since the orientation of the principal strains is not generally obvious, placement of a strain gauge will most likely not be on a principal axis. Principal strains and their orientations may be determined by the use of three gauges mounted at known angles from each other. A rosette gauge has an arrangement of three gauges intended to measure strains in three directions. The delta rosette has gauges spaced 120° apart while the rectangular rosette has gauges oriented 45° apart (Fig 1). The equations for calculating the principal strains and their orientation with respect to the rosette are given by the equations in your data sheet.

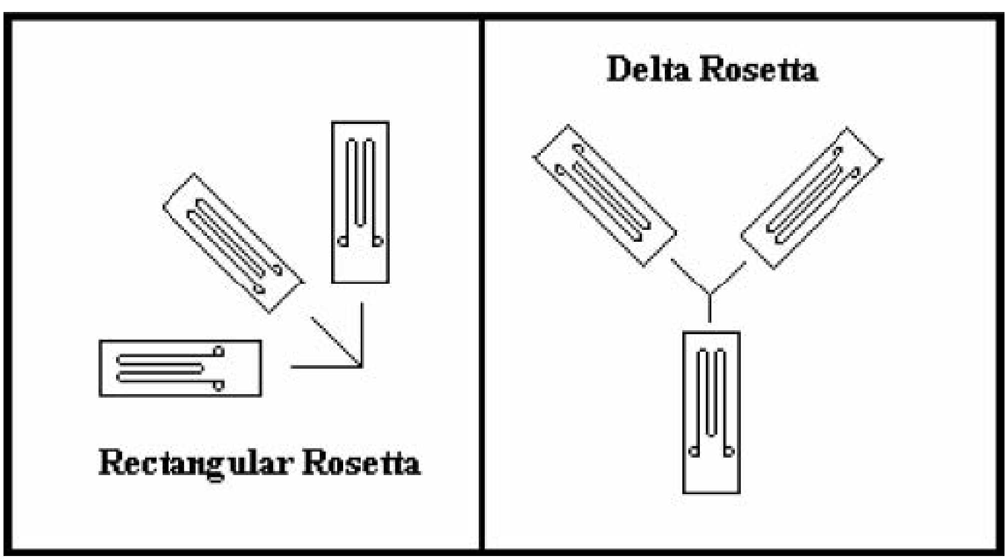


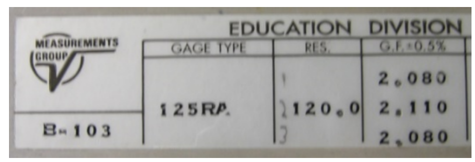
Fig 1 - Rosette Strain Gauges

DAQ and LabView VI setup

1. Insert the NI 9219 module into DAQ. Connect DAQ to the computer using the USB cable.
2. Connect one strain gauge to the Channel 0 (ai-0) at pin 3 (red wire) and 5 (white wire). This is the quarter bridge connection. Refer to NI 9219 module – Getting Started Guide, Page 12.
3. Open the LabView VI. Make sure to set the correct Gauge Factor in the VI for the strain gauges used in the experiment.
4. Run the VI to take the strain reading with no load on it. Copy the strain reading and paste it into the ZERO reading and enter. This is done to zero out the readings for the reference point.
5. Add weights and note down the strain readings. Add first weight of 0.5 kgs on the end of the beam on the beam. This will record the first strain reading. Keep adding the weights in 0.5 kg increments up to 2 kgs and record each strain reading.
   NOTE that the reading is in $\mu\varepsilon$, $1\mu\varepsilon = 1\times10^{-6}\varepsilon$)

Data Sheet
Material: Aluminum
Theoretical Poisson's Ratio, ν: 0.33
Theoretical Modulus of Elasticity, E: 69,000 MPa

Gage Factors are labeled on the specimen.
Gage #1~#3



Gauge Data:
Gauge Factor, gauge 1:
Gauge Factor, gauge 2:
Gauge Factor, gauge 3:

Specimen Dimensions:

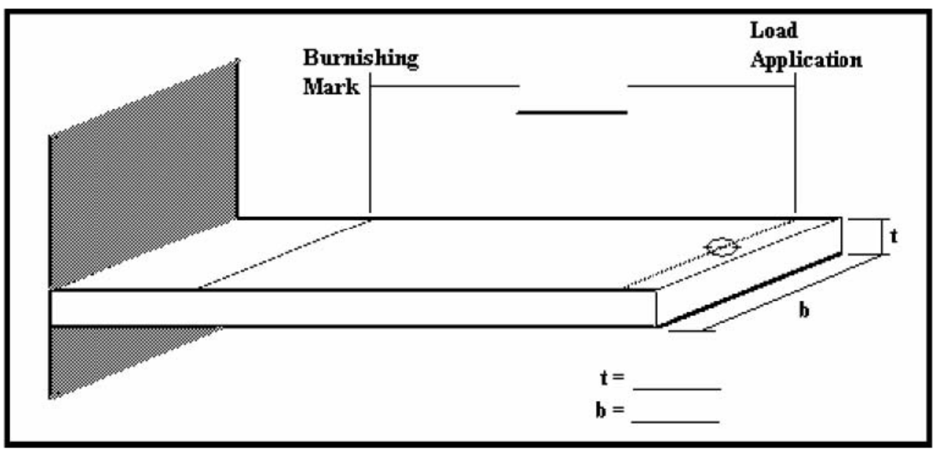


Fig 2 - Experimental Setup

b = _______ mm t = ________ mm L = ________ mm I = ________ mm^4

Note: Burnishing mark can be found under the strain gage rosette

Observation Table:

_Load (Kg)	Experimental		
	$\varepsilon_1(\mu\varepsilon)$	$\varepsilon_2(\mu\varepsilon)$	$\varepsilon_3(\mu\varepsilon)$
0.5			
1.0			
1.5			

Theoretical Calculations:

1. **Principal Stresses:**

The stress state for pure bending is given by:

$$\sigma_x = \frac{Mc}{I} = \frac{6PL}{bt^2}\ ;\ \sigma_y = 0\ ;\ \tau_{xy} = 0$$

Consequently, the principal stresses can be found from the stress transformation to be:

$$\sigma_p = \frac{6PL}{bt^2}\ ;\ \sigma_q = 0\ ;$$

where,
M = bending moment at gauge centerline, (N-mm);
c = semi-thickness of beam, (mm);
I = $bt^3/12$=moment of inertia of beam cross section, (mm^4);
P = load, (N)
L = effective beam length, that is, length from gauge centerline to the applied load, (mm)
b = beam width, (mm); t = beam thickness, (mm)
t= thickness of the beam, (mm);

2. **Principal Strains:**

Applying Hooke's law to the principal stresses, principal strains are given by:

$$\varepsilon_p = \frac{\sigma_p}{E}$$

$$\varepsilon_q = \frac{-\upsilon\sigma_p}{E}$$

Computation Table I:

		Theoretical Data				
Load (Kg)	Load (N)	$\sigma_p(MPa)$	$\sigma_q(MPa)$	ε_p (με)	ε_q (με)	Poisson's Ratio (ν)
0.5			0			
1.0			0			
1.5			0			

Experimental Calculations:

1. **Computation of Principal Strains (Rectangular Rosette):**

Maximum Principal Strain (ε_p) and Minimum Principal Strain (ε_q) are given by:

$$A = \frac{\varepsilon_1 + \varepsilon_3}{2}$$

$$B = \frac{1}{\sqrt{2}}\sqrt{(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2}$$

$$\varepsilon_p = A + B$$

$$\varepsilon_q = A - B$$

2. **Computation of Poisson's ratio and principal stresses:**

$$\upsilon = -\frac{\varepsilon_q}{\varepsilon_p}$$

$$\sigma_p = \frac{E}{\left(1 - \upsilon^2\right)}\left(\varepsilon_p + \upsilon\varepsilon_q\right)$$

$$\sigma_q = \frac{E}{\left(1 - \upsilon^2\right)}\left(\varepsilon_q + \upsilon\varepsilon_p\right)$$

Note: In order to obtain stresses in MPa, input Young's Modulus in MPa and convert micro strain to strain by multiplying the strain terms by 10^{-6}

3. **Computation of angles between <u>gauge 1 axis</u> and principal axes:**

$$\theta_{p,q} = \frac{1}{2}\tan^{-1}\left(\frac{2\varepsilon_2 - \varepsilon_1 - \varepsilon_3}{\varepsilon_1 - \varepsilon_3}\right)$$

Convert the angle from radians to degrees.

Computation Table II:

			Experimental Data						
Load (Kg)	A	B	ε_p (με)	ε_q (με)	Poisson's Ratio (ν)	σ_p	σ_q	$\theta_{p,q}$
0.5								
1.0								
1.5								

Summation Table:

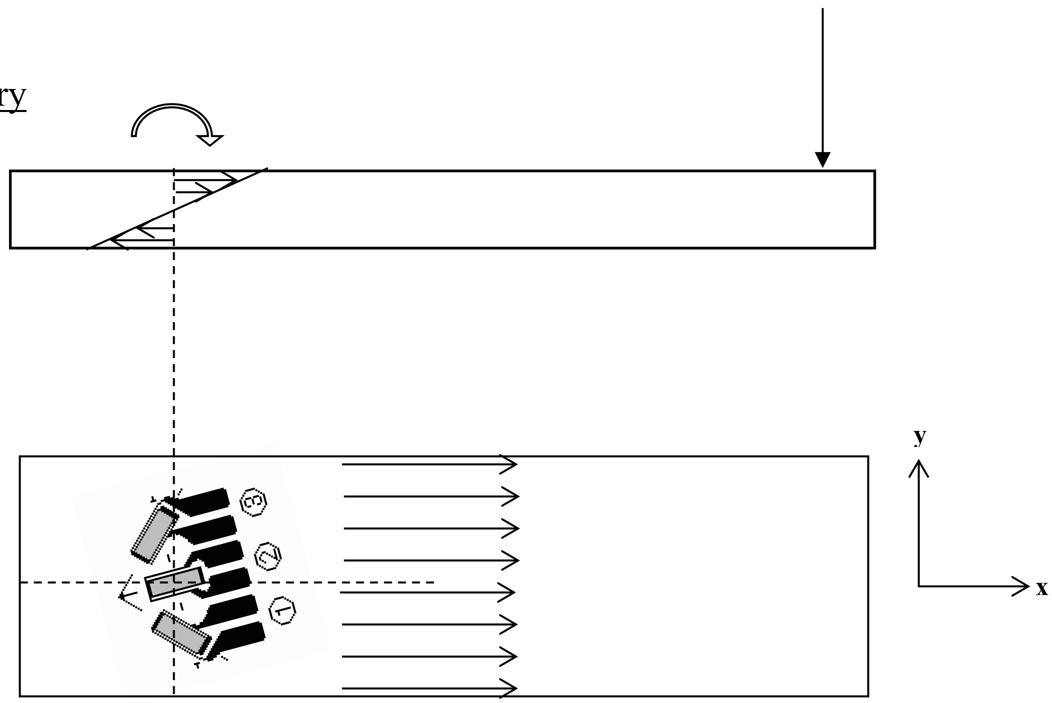
	Theoretical					Experimental					Error (%)			
Load (kg)	σ_p (MPa)	ν	σ_q (MPa)	ε_p (με)	ε_q (με)	σ_p (MPa)	ν	σ_q (MPa)	ε_p (με)	ε_q (με)	ν	σ_p	ε_p	ε_q

0.5		0.33	0										
1.0		0.33	0										
1.5		0.33	0										

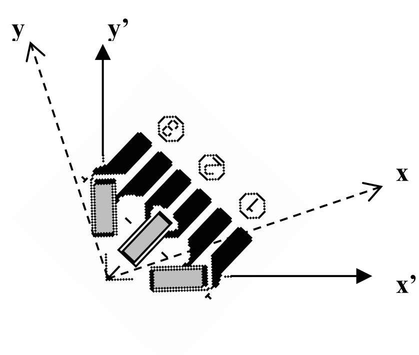
Required:

Calculate Poisson's ratio, Principal Stresses, Principal Strains and the Principal angles and respective errors.

Theory



The stress due to moment should be uniform far away from the point load, so the stress should uniformly act on x-axial at the strain gage area.



Using strain measured from Rectangular Rosette to find the Principal Strains

The strain data from the Rosette Gage#1, Gage#2, and Gage#3 are ε_1, ε_2, and ε_3 respectively. By using the transformation function[1] that the strain state can be calculated at x' & y' coordinate.

[1] Please refer Chapter 10-5 Strain Rosettes (p.541) of the book ***Mechanics of Materials*** (7th Edition) by R.C. Hibbeler

$$\begin{aligned}\varepsilon_{x'} &= \varepsilon_1 \\ \varepsilon_{y'} &= \varepsilon_3 \\ \gamma_{x'y'} &= 2\varepsilon_2 - (\varepsilon_1 + \varepsilon_3)\end{aligned} \qquad (1)$$

The principal strains of these strain state are

$$\varepsilon_{p,q} = \frac{\varepsilon_{x'} + \varepsilon_{y'}}{2} \pm \sqrt{\left(\frac{\varepsilon_{x'} - \varepsilon_{y'}}{2}\right)^2 + \left(\frac{\gamma_{x'y'}}{2}\right)^2}$$

$$\tan 2\theta_p = \frac{\gamma_{x'y'}}{\varepsilon_{x'} - \varepsilon_{y'}} \qquad (2)$$

where ε_p & ε_q are the max & min pricipal strains,

θ_p is the angle between Gage#1 axis and principal axes

Substitute (1) into (2)

$$\varepsilon_{p,q} = \frac{\varepsilon_1 + \varepsilon_3}{2} \pm \frac{1}{\sqrt{2}}\sqrt{(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2}$$

$$\tan 2\theta_p = \frac{2\varepsilon_2 - \varepsilon_1 - \varepsilon_3}{\varepsilon_1 - \varepsilon_3} \qquad (3)$$

<u>Some useful formulae for Theoretical Calculations</u>

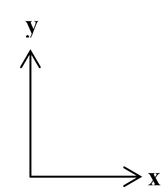
<u>Hooke's Law</u>

$$\begin{aligned}\varepsilon_x &= \frac{1}{E}[\sigma_x - \upsilon\sigma_y] \\ \varepsilon_y &= \frac{1}{E}[\sigma_y - \upsilon\sigma_x] \\ \gamma_{xy} &= \frac{2(1+\upsilon)}{E}\tau_{xy}\end{aligned} \qquad (4)$$

<u>Principal Stress</u>

$$\sigma_{p,q} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + (\tau_{xy})^2} \qquad (5)$$

where σ_p & σ_q are the max & min pricipal stresses



For a stress system of Lab #7, the stresses at strain gage area are $\sigma_x = \sigma = \frac{6PL}{bt^2}$, $\sigma_y = 0$, $\tau_{xy} = 0$. Substitute the values into (4) to find the strain, and then use the equation (2) to find the theoretical principal strains. Also, by using $\sigma_x = \sigma = \frac{6PL}{bt^2}$, $\sigma_y = 0$, $\tau_{xy} = 0$ and the equation (5), the theoretical principal stresses can be found.